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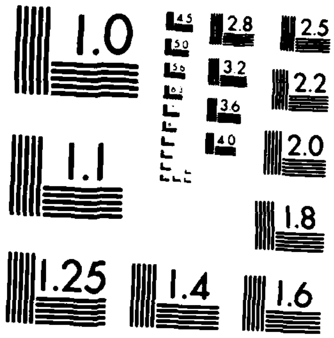

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Annual Report on Electronics Research at The University of Texas at Austin

No. 31

For the period April 1, 1983 through March 31, 1984

JOINT SERVICES ELECTRONICS PROGRAM

Research Contract AFOSR F49620-82-C-0033

May 15, 1984

Bureau of Engineering Research
The University of Texas at Austin
Austin, Texas 78712

The Electronics Research Center at The University of Texas at Austin consists of interdisciplinary laboratories in which graduate faculty members, Master and PhD candidates from numerous academic disciplines conduct research. The disciplines represented in this report include information electronics, solid state electronics, quantum electronics, and electromagnetics.

The research summarized in this report was supported by the Department of Defense's JOINT SERVICES ELECTRONICS PROGRAM (U.S. Army, U.S. Navy, and the U.S. Air Force) through the Research Contract AFOSR F49620-82-C-0033. This program is monitored by the Department of Defense's JSEP Technical Coordinating Committee consisting of representatives from the U.S. Army Research Office, Office of Naval Research and the U.S. Air Force Office of Scientific Research.

Annual Report on Electronics Research

at The University of Texas at Austin

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JOINT SERVICES ELECTRONICS PROGRAM
Research Contract AFOSR F49620-82-C-0033

Submitted by Edward J. Powers
on Behalf of the Faculty and Staff
of the Electronics Research Center

May 15, 1984

ELECTRONICS RESEARCH CENTER

Bureau of Engineering Research
The University of Texas at Austin
Austin, Texas 78712

Approved for public release; distribution unlimited.

ABSTRACT

This report summarizes progress on projects carried out at the Electronics Research Center at The University of Texas at Austin and which were supported by the Joint Services Electronics Program. In the area of Information Electronics progress is reported for projects involving (1) nonlinear estimation and detection, (2) electronic time-variant signal processing, and (3) digital time series analysis with applications to nonlinear wave phenomena.

In the Solid State Electronics area recent findings in (1) solid state interface reactions and instabilities, (2) electronic properties and structure of metal silicides and interfaces, and (3) implantation and interface properties of InP and related compounds are described.

In the Quantum Electronics area progress is presented for the following projects: (1) quantum effects in laser induced damage, (2) nonlinear Raman scattering from molecular ions and (3) nonlinear optical interactions.

In the Electromagnetics area progress in guided waves in composite structures is summarized.

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PERSONNEL AND RESEARCH AREAS

ELECTRONICS RESEARCH CENTER

Phone: (512) 471-3954

Administration for the Joint Services Electronics Program

Professor Edward J. Powers, Director
Professor Rodger M. Walser, Assoc. Director

Electronics Research Center Staff

Connie Finger, Administrative Assistant I
Jan White, Accountant I

Coordinators For Research Areas

Professor S.I. Marcus, Information Electronics
Professor R.M. Walser, Solid State Electronics
Professor M.F. Becker, Quantum Electronics
Professor T. Itoh, Electromagnetics

Faculty

Information Electronics:

J.K. Aggarwal, Professor, EE, 471-1369
S.I. Marcus, Associate Professor, EE, 471-3265
E.J. Powers, Professor, EE, 471-1430
J.L. Speyer, Professor, Aerospace, 471-1356

Solid State Electronics:

M.F. Becker, Associate Professor, EE, 471-3628
R.W. Bene', Professor, EE, 471-1225
J.L. Erskine, Associate Professor, Physics 471-1464
B.G. Streetman, Professor, EE, 471-1754
R.M. Walser, Professor, EE, 471-5733

QUANTUM ELECTRONICS:

M.F. Becker, Associate Professor, EE, 471-3628
M. Fink, Professor, Physics, 471-5747
J. Keto, Associate Professor, Physics, 471-4151
H.J. Kimble, Assistant Professor, Physics, 471-1668
R.M. Walser, Professor, EE, 471-5733

PERSONNEL AND RESEARCH AREAS

Electromagnetics:

T. Itoh, Professor, EE, 471-1072

Postdoctoral Research Associate and Research Engineer Associate

Jae Y. Hong, EE, Research Engineer Associate V
Albert T. Rosenberger, Physics, Postdoctoral Research Associate

Research Assistants

John Beall, EE
Norbert Boewering, Physics
*T.L. Boyd, Physics
Yu-Jeng Chang, EE
Chien-Hwei Chen, EE
DooWhan Choi, EE
Dan Coffman, Physics
Joseph B. Comunale, Physics
*Hassan Ehsani, EE
Kie Bum Eom, EE
Craig Farley, EE
*Steven Fry, EE
Yoshiro Fukuoka, EE
*D.E. Grant, Physics
Jessy Grizzle, EE
*C.C. Han, EE
*John Hartley, Physics
*Jim Higdon, Physics
*Austin Huang, EE
Yong Jee, EE
Yoon Kyoo Jhee, EE
Suhas Ketkar, Physics
Tae Sung Kim, EE
Taiho Koh, EE
*Y.H. Ku, EE
Shih-Ked Lee, EE
Tzong Leou, EE
Bin-Wah Lin, EE
Michael Magee, EE
Richard Mawhorter, Physics
*Jabez J. McClelland, Physics
Bruce Miller, Physics
Raymond Munroe, Physics
Nagaraj Nandhakumar, EE
*Luis A. Orozco, Physics
Segeun Park, EE
Sung Han Park, EE
T.D. Raymond, Physics
Hyung Soon Shin, EE
*Nag Un Song
Taek Song, Aerospace
Baba Vemuri, EE
Lingtao Wang, EE
John White, Aerospace
Sudhakar Yalamanchilli, EE
Hwa-Yueh Yang, EE

*Denotes persons who have contributed to JSEP projects, but who have not been paid out of JSEP funds (e.g., students on fellowships).

PERSONNEL AND RESEARCH AREAS

Advanced Degrees Awarded

John M. Beall, EE, Ph.D., May 1983, "The Local Wavenumber Spectrum and Its Applications in the Study of Turbulence and Noise".

Yu-Jeng Chang, Physics, Ph.D., August 1983, "Electronic Properties and Interfaced Microstructures of Nickel Silicides on Silicon Substrates."

D.E. Grant, Physics, M.S., December 1983, "Absorptive Optical Bistability with Two-Level Atoms."

Jessy W. Grizzle, EE, Ph.D., December 1983, "The Structure and Optimization of Nonlinear Control Systems Processing Symmetries".

Yen-Hui Ku, EE, M.S., August 1983, "Stress in Ultrathin Cobalt Film on Silicon."

Bih-Wan Lin, EE, M.S., December 1983, "Adaptive Control of Priority Assignment in Queueing Systems."

Bruce Reagan Miller, Physics, Ph.D., December 1983, "On The Accuracy of Molecular Structures Determined From Precise Electron Diffraction Data."

T.D. Raymond, Physics, Ph.D., August 1983, "Two Photon Spectroscopy of the 6P Manifold of Xenon."

Taek L. Song, Aerospace Engineering, Ph.D., December 1983, "A Stochastic Analysis of A Modified Gain Extended Kalman Filter."

L.A. Wu, Physics, M.S., December 1983, "The Role of Phase in Second Harmonic Generation within an Optical Cavity".

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES, AND REPORTS

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

JOURNAL ARTICLES

*R.J. Mawhorter, M. Fink, "The Vibrationally-Averaged Temperature Dependent Structure of Polyatomic Molecules II SO_2," J. Chem. Phys. 79, 3292 (1983).

J. Ganz, A. Siegel, W. Bussert, K. Harth, M.W. Ruf, H. Hotop, J. Geiger and M. Fink, "On the Ne($2p^5$ns', nd') Autoionization Resonances: High Resolution Measurement and Quantum Defect Analysis", J. Physics B, 16, 1569-1576 (1983).

Peter Pulay, R. Mawhorter, D.A. Kohl and M. Fink, "AB INITIO Hartree-Fock Calculations of the Elastic Electron Scattering Cross Section of Sulphur Hexafluoride," J. Chem. Phys., 79, 185 (1983).

*D.E. Grant and H.J. Kimble, "Transient Response in Absorptive Bistability," Opt. Commun., 44, 415 (1983).

*A.T. Rosenberger, L.A. Osozco, and H.J. Kimble, "Observation of Absorptive Bistability with Two-Level Atoms in a Ring Cavity," Phys. Rev. A28, 2569 (1983).

*R.J. Mawhorter, M. Fink and B.T. Archer, "An Experimental Determination of the Vibrationally-Averaged, Temperature-Dependent Structure of CO_2," J. Chem. Phys. 79, 170 (1983).

*Chien-Yu Kuo and J.W. Keto, "Dissociative Recombination of Electrons in Electron Beam Excited Argon and High Densities", J. Chem. Phys. 78, 1851 (1983).

*S.N. Ketkar, M. Fink and R.A. Bonham, "High Energy Electron Scattering from Helium," Phys. Rev. A27, 806-809 (1983).

A.M. Turner and J.L. Erskine, "Magnetic Exchange Splitting and Band Dispersion of Surface States on Fe(100)," Phys. Rev. B28, 5628 (1983).

H.A. Stevens, A.M. Turner, A.W. Donoho and J.L. Erskine, "Angle-Resolving Photoelectron Energy Analyzer: Mode Calculations, Ray Tracing, Analysis and Performance Evaluation," J. Electron Spectroscopy and Related Phenom. 32, 327 (1983).

W.N. Martin and J.K. Aggarwal, "Dynamic Scene Analysis," in the book Image Sequence Processing and Dynamic Scene Analysis edited by T.S. Huang, Springer-Verlag, pp. 40-73 (1983).

*Funded entirely or in part by the Joint Services Electronics Program.

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

B.M. Davies and J.L. Erskine, "Azimuthal Dependence of Impact Scattering in Electron Energy Loss Spectroscopy," J. Electron Spectroscopy and Related Phenom. 29, 323 (1983).

R.L. Strong, B. Firey, F.W. de Wette and J.L. Erskine, "Adsorbate Structure Modeling Based on Electron Energy Loss Spectroscopy and Lattice Dynamical Calculations: Applications to O/Al(111)," J. Electron Spectroscopy and Related Phenom. 29, 187 (1983).

*Yu-Jeng Chang and J.L. Erskine, "First Phase Nickel Silicide Nucleation and Interface Structure at Si(100) Surfaces," J. Vacuum Science and Technol. A1, 1193 (1983).

*Yu-Jeng Chang and J.L. Erskine, "Diffusion Layers and the Shottky Barrier Height in Nickel Silicide-Silicon Interfaces," Phys. Rev. B28, 5766 (1983).

J. Rivera and T. Itoh, "Analysis of an Electromagnetically Coupled Patch Antenna," Electromagnetics, Vol. 3, No. 4,Fall 1983.

J.-F. Miao and T. Itoh, "Coupling Between Microstrip Line and Image Guide Through Small Apertures in the Common Ground Plane," IEEE Trans. Microwave Theory and Techniques, vol. MTT-31, no. 4, 361-363 (April 1983).

J.D. Oberstar and B.G. Streetman, "Thin Film Encapsulants for Annealing GaAs and InP," Thin Solid Films 103, 17-26 (May 13, 1983).

R.W. Miksad, F.L. Jones and E.J. Powers, "Measurements of Nonlinear Interactions During Natural Transition of a Symmetric Wake," Phys. Fluids 26, 6 (June 1983).

S. Banerjee and B.G. Streetman, "Theoretical and Experimental Study of Swept Line Electron Beam Annealing of Semiconductors," J. Appl. Phys. 54, 2947-2955 (June 1983).

*Y. Fukuoka, Y.C. Shih and T. Itoh, "Analysis of Slow-Wave Coplanar Waveguide for Monolithic Integrated Circuits," IEEE Trans. Microwave Theory and Techniques, vol. MTT-31, no. 7, pp. 567-573, (July 1983).

*G.L. Blankenship, C.-H. Liu and S.I. Marcus, "Asymptotic Expansions and Lie Algebras for Some Nonlinear Filtering Problems," IEEE Transactions on Automatic Control, vol. AC-28, 787-797 (July 1983).

S.K. Banerjee and B.G. Streetman, "Electron and Hole Traps in Silicon-on-Oxide Grown Using Lateral Epitaxy By Seeded Solidification," J.

Phys. D: Applied Physics 16, L215-L218 (November 1983).

*O. Hernandez-Lerma and S.I. Marcus, "Adaptive Control of Service in Queueing Systems," Systems and Control Letters, vol. 3, 283-289 (November 1983).

S.K. Banerjee, R.Y. DeJule, K.J. Soda and B.G. Streetman, "Planar Be-Implanted GaAs Junction Formation Using Swept-Line Electron Beam Annealing," IEEE Trans. Electron Dev. ED-30, 1755-1760 (December 1983).

Y.C. Shih and T. Itoh, "E-Plane Filters with Finite-Thickness Septa," IEEE Trans. Microwave Theory and Techniques, vol. MTT-31, no. 12, 1009-1013 (December 1983).

*Y. Fukuoka and T. Itoh, "Slow-Wave Coplanar Waveguide on Periodically Doped Semiconductor Substrates," IEEE Trans. Microwave Theory and Techniques, vol. MTT-31, no. 12, 1013-1017 (December 1983).

L. Su, T. Itoh and J. Rivera, "Design of an Overlay Directional Coupler by a Full-Wave Analysis," IEEE Trans. Microwave Theory and Techniques, vol. MTT-31, no. 12, pp. 1017-1022 (December 1983).

*M. Hazewinkel, S.I. Marcus and H.J. Sussmann, "Non-Existence of Finite Dimensional Filters for Conditional Statistics of the Cubic Sensor Problem," Systems and Control Letters, vol. 3, 331-340 (December 1983).

A.M. Turner, A.W. Donoho and J.L. Erskine, "Experimental Bulk Electronic Properties of Ferromagnetic Iron," Phys. Rev. B29, 2986 (1984).

W.B. Zhou and T. Itoh, "Field Distribution in the Trapped Image Guide," Electromagnetics, Vol. 4, No. 1,(Spring 1984).

T.E. Dietz, K.R. Diller and J.K. Aggarwal, "Automated Computer Evaluation of Time-Varying Cryomicroscopical Images," Cryobiology, vol. 21, 200-208 (1984).

J.K. Aggarwal, "Motion and Time Varying Imagery," Computer Graphics, vol. 18, no. 1, 20-21 (January 1984).

K.D. Stephan and T. Itoh, "A Planar Quasi-Optical Subharmonic Mixer Characterized by Isotropic Conversion Loss," IEEE Trans. Microwave Theory and Techniques, vol. MTT-32, no. 1, 97-102 (January 1984).

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

*C.W. Farley and B.G. Streetman, "The Role of Defects in the Diffusion and Activation of Impurities in Ion-Implanted Semiconductors," J. Electr. Mater. 13, 401-436 (March 1984).

S.J. Levinson, J.M. Beall, E.J. Powers and Roger D. Bengtson, "Space-Time Statistics of the Turbulence in a Tokamak Edge Plasma," Nuclear Fusion, in press.

Shang-De Xie, M. Fink and D.A. Kohl, "Basis Set Dependence of Ab Initio SCF Elastic Born Scattering Cross Sections for Electrons on C_2H_4," J. Chem. Phys., in press.

D.A. Kohl, P. Pulay and M. Fink, "On the Calculations of Electron Scattering Cross Sections from Molecular Wavefunctions," Theo. Chem., in press.

*J.L. Erskine and Yu-Jeng Chang, "Selective Growth, Diffusion Layers and the Schottky Barrier Height in Nickel Silicide-Silicon Interfaces," Solid Thin Films, in press.

*L.W. Frommhold, J.W. Keto and Michael H. Proffitt, "Diatom Polarizabilities from New Measurements of Collision-Induced Raman Spectra of the Noble Gases," J. Can. Phys., 59, in press.

*T.Y. Leou and J.K. Aggarwal, "Recursive Implementation of LTV Filters - Frozen-Time Transfer Function vs Generalized Transfer Function," to appear in IEEE Proceedings.

*S. Park and J.K. Aggarwal, "A Simple Form Synthesis of Linear Time-Variant Digital Filters via Spectral Decomposition of its Impulse Response," to appear in Journal of the Franklin Institute.

Jabez J. McClelland and M. Fink, "Correlation Effects in Neon Studied by Elastic and Inelastic High Energy Scattering," Phys. Rev. A, submitted.

*Y.H. Ku and R.W. Bene', "Stress in Ultrathin Cobalt Films on Silicon," submitted to J. Applied Physics.

A.M. Turner and J.L. Erskine, "Surface Electronic Properties of Fe(100)," submitted to Phys. Rev. B.

*T.D. Raymond, S.T. Walsh and J.W. Keto, "A Narrowband Dye Laser with a Large Scan Range," submitted to Applied Physics.

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

Bruce R. Miller and M. Fink, "The Vibrationally Averaged Temperature Dependent Structure of Polyatomic Molecules III. N_2O", J. Chem. Phys., accepted.

R.L. Strong and J.L. Erskine, "A New Lens System for Surface Vibrational Spectroscopy at High Impact Energies," submitted to Rev. Sci. Inst.

*R.W. Bene', G.S. Lee and N.I. Cho, "1/F Noise in Ultrathin Co and Ni Films on Si Substrates," in preparation.

*R.W. Bene' and H. Ehsani, "TED Studies of Ultrathin Pd Films on GaAs Substrates," in preparation.

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

TECHNICAL PRESENTATIONS

ACM Siggraph/Sigart Workshop on Motion-
Representation and Perception
Toronto, Canada
April 1983

J.K. Aggarwal, "3-D Computer Vision - An Introduction."

NASA Symposium on Computer Aided
Geometry Modeling
Hampton, VA
April 1983

W.N. Martin, B. Gil and J.K. Aggarwal, "Volumetric Representation for Object Model Acquisition."

Seminar
University of Texas at Dallas
April 8, 1983

H.J. Kimble, "Optical Bistability with Intracavity Atomic Beams."

1983 IEEE International Conference
on Acoustics, Speech and Signal Processing
Boston, Massachusetts
April 14-16, 1983

Taiho Koh and E.J. Powers, "Adaptive Nonlinear Digital Filter with Lattice Orthogonalization."

Colloquium of the Electrical
Engineering Department
University of Notre Dame
South Bend, Indiana
April 25, 1983

*S.I. Marcus, "Nonlinear Filtering: Pathwise Solutions, Finite Dimensional Filters, and Approximations."

*Funded entirely or in part by the Joint Services Electronics Program.

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

Conference on Lasers and Electro-Optics
Baltimore, Maryland
May 1983

*M.F. Becker, Y.-K. Jhee, M. Bordelon, and R.M. Walser, "Charged Particle Exoemission From Silicon During Multi-Pulse Laser Induced Damage."

Offshore Technology Conference
Houston, Texas
May 2-5, 1983

R.W. Miksad, D.W. Choi, E.J. Powers and F.J. Fischer, "Applications of Digital Complex Demodulation Techniques to Low Frequency Nonlinear Drift Forces in Irregular Seas."

1983 IEEE International Conference
on Plasma Science
San Diego, California
May 23-25, 1983

S.B. Kim, T.P. Kochanski, J.A. Snipes, G.R. Joyce and E.J. Powers, "Observation of Nonlinear Mode Coupling of a Low Frequency MHD Oscillation in TEXT."

E.J. Powers, "Applications of Digital Time Series Analysis to Plasma Fluctuation Diagnostics."

S.J. Levinson, J.M. Beall, E.J. Powers and R.D. Bengtson, "Edge Turbulence in the PRETEXT Tokamak."

1983 International Microwave Symposium
Boston, Massachusetts
May 31-June 3, 1983

*Y. Fukuoka and T. Itoh, "Slow Wave Coplanar Waveguide on Periodically Doped Semiconductor Substrates."

Trends and Application 1983 Conference
Gaithersburg, MD
May 1983

J. Courtney and J.K. Aggarwal, "Robot Guidance Using Computer Vision."

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

1983 International Symposium on
Antennas and Propagation
Houston, Texas
May 23-26, 1983

J. Rivera and T. Itoh, "Analysis of an Electromagnetically Coupled Patch Antenna."

1983 International Microwave Symposium
Boston, Massachusetts
May 31-June 3, 1983

Y.C. Shih and T. Itoh, "E-Plane Filters with Finite-Thickness Septa."

L. Su, T. Itoh and J. Rivera, "Design of An Overlay Directional Coupler by a Full-Wave Analysis."

W.B. Zhou and T. Itoh, "Field Distributions in the Trapped Image Guide."

IEEE Computer Society Conference
on Computer Vision and Pattern Recognition
Washington, D.C.
June 1983

C.H. Chien and J.K. Aggarwal, "A Normalized Quadtree Representation."

M. Magee and J.K. Aggarwal, "Intensity Guided Range Sensing Recognition of Three-Dimensional Objects."

Y.C. Kim and J.K. Aggarwal, "Rectangular Coding of Binary Images."

Invited Talk
Fifth Rochester Conference on
Coherence and Quantum Optics
and Topical Meeting on
Optical Bistability
Rochester, New York
June 13-17, 1983

H.J. Kimble, "Optical Bistability with Two-Level Atoms."

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

III-V Research Strategy
Workshop for Digital IC Applications
Research Triangle Park, N.C.
June 14, 1983

B.G. Streetman, "Ion Implantation Research."

1983 Electronic Materials Conference (AIME)
Burlington, VT
June 23, 1983

B.G. Streetman, "The Role of Defects in the Diffusion of Impurities in Ion Implanted Semiconductors."

Colloquia
University of Kaiserslautern
Germany

M. Fink. "Temperature Dependent Molecular Structure Parameters."

Naval Underwater Systems Center
New London, Connecticut
July 12, 1983

E.J. Powers, "Application of Higher-Order Spectra in Analyzing and Interpreting Nonlinear Time Series Data."

UCLA Short Course on Advanced Scattering
Analysis of Microwave Networks with Applications
UCLA Extension Course No. Engineering 881.61
Los Angeles, CA
July 25-29, 1983

*T. Itoh, "Generalized Scattering Matrix Technique."

International Society for
Optical Engineering Annual Symposium
San Diego, CA
August 1983

S. Yalamanchili and J.K. Aggarwal, "A Model for Parallel Image Processing."

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

3-D Workshop of the American Association
for Artificial Intelligence
Washington, DC
August 1983

M. Magee and J.K. Aggarwal, "Intensity Guided Range Sensing Recognition of Three-Dimensional Objects."

SPIE
San Diego, CA
August 22-26, 1983

T. Itoh and K.D. Stephan, "Quasi-Optical Planar Mixers for Millimeter-Wave Imaging Applications."

13th European Microwave Conference
Nurnberg, West Germany
September 5-8, 1983

*Y. Fukuoka and T. Itoh, "Design Consideration of Uniform and Periodic Coplanar Schottky Variable Shifter."

S.W. Yun and T. Itoh, "A Novel Distributed Millimeter-Wave Isolator."

BRASIL OFFSHORE '83
International Symposium on Offshore Engineering
Rio de Janeiro, Brazil
September 12-16, 1983

*T. Koh, E.J. Powers, R.W. Miksad and F.J. Fischer, "An Approach To Time Domain Modelling of Nonlinear Drift Oscillations in Random Seas."

Colloquium
Invited Talk
Heriod-Watt University
Edinburg, Scotland
September 15, 1983

H.J. Kimble, "Atomic Cooperativity in Optical Bistability."

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

16th Annual Electronics and
Aerospace Conference and Exposition
Washington, D.C.
September 19-21,1983

*J.Y. Hong and E.J. Powers, "Detection of Weak Third Harmonic Backscatter from Nonlinear Metal Targets."

Venture Research Science Meeting
Sponsored by British Petroleum, Int.
London, England
September 20-21, 1983

H.J. Kimble, "Nonequilibrium Phase Transition in Optical Systems."

Physics Colloquium
Texas A&M University
College Station, Texas
October 1983

J.W. Keto, "Laser Probes of Reactions in Half-Collision."

1983 Annual Meeting of the
Optical Society of America
New Orleans, LA.
October 17-20, 1983

H.J. Kimble, A. Mezzacappa and P.W. Milonni, "Time Dependence of Photon Correlations in a Three-Level Atomic Cascade."

H.J. Kimble, L.A. Orozco and A.T. Rosenberger, "Evolution of Hysteresis in Dispersive Bistability with Two-Level Atoms."

H.J. Kimble, A.T. Rosenberger and L.A. Orozco, "Anomalous Behavior on the Upper Branch in Optical Bistability."

15th ASTM Laser Damage Symposium
Boulder, CO.
November 1983

*M.F. Becker, F.E. Domann, A.F. Stewart and A.H. Guenther, "Charge Emission and Related Precursor Events Associated with Laser Damage."

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

Instituto de Fisica
Universidade Federal Fluminense
Rio de Janeiro, Brazil
September 19, 1983

E.J. Powers, "Applications of Digital Time Series Analysis to Plasma Fluctuation Diagnostics."

Instituto de Fisica
University of Sao Paulo
Sao Paulo, Brazil
September 20, 1983

E.J. Powers, "Applications of Digital Time Series Analysis to Plasma Fluctuation Diagnostics."

Instituto de Fisica
University of Campinas
Campinas, Brazil
September 21, 1983

E.J. Powers, "Application of Digital Time Series Analysis to Plasma Fluctuation Data."

Colloquium
University of Arkansas
November 4, 1983

H.J. Kimble, "Optical Bistability with Two-Level Atoms: Theory Meets Experiment."

25th Annual Meeting of the
Division of Plasma Physics
Los Angeles, California
November 7-11, 1983

S.B. Kim, T.P. Kochanski, J. Snipes, E.J. Powers, and P. Phillips, "Evolution of MHD Mode Structure in TEXT."

S.J. Levinson, J. Beall, E.J. Powers, Roger D. Bengtson and K. Nelin, "Edge Turbulence in TEXT and PRETEXT."

Ch.P. Ritz, S.J. Levinson, E.J. Powers, and Roger D. Bengtson, "An Approach to Estimate Wave-Wave Nonlinear Coupling Coefficients in a Turbulent Plasma."

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

Electrical and Computer Engineering
Department Seminar
University of Massachusetts
Amherst, MA
November 15, 1983

*T. Itoh, "MIC Transmission Lines with Composite Materials."

Invited Talk
Venture Research Material Sciences Meeting
London, England
November 23, 1983

H.J. Kimble, "Nonequilibrium Phase Transition in Optical Systems."

Invited Talk
Royal Signals and Radar Establishment
Malvern, England
November 25, 1983

H.J. Kimble, "Optical Bistability with Intracavity Atomic Beams."

IEEE Conference on Decision and Control
San Antonio, Texas
December 1983

*T.Y. Leou and J.K. Aggarwal, "Difference Equation Implementations of Time Variant Digital Filters."

MCC Presentation
Austin, Texas
December 6, 1983

R.W. Bene', "Systematics of Solid State Interface Development between Thin Metal Films and Semiconductor Substrates."

8th International Conference on
Infrared and Millimeter Waves
Miami Beach, Florida
December 12-17, 1983

K.D. Stephan and T. Itoh, "Isotropic Conversion Loss as a Measure of Quasi-Optical Mixer Efficiency."

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

Invited Talk
1984 Joint APS/AAPT Meeting
San Antonio, Texas
January 30, 1984

M. Fink, "Correlation and Binding Effects in Molecules Studies by High Energy Electron Diffraction."

2nd International Modal Analysis Conference
Orlando, Florida
February 6-9, 1984

DooWhan Choi, Jung-Hua Chang, R.O. Stearman and E.J. Powers, "Bispectral Identification of Nonlinear Mode Interactions."

Department Colloquium
University of Texas at Arlington
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J.L. Erskine, "Electron Energy Loss Studies of Ordered Structures at Metal Surfaces."

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*R.W. Bene', "Solid State Interface Reactions and Instabilities."

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I. INFORMATION ELECTRONICS

THE UNIVERSITY OF TEXAS AT AUSTIN ELECTRONICS RESEARCH CENTER
INFORMATION ELECTRONICS

Research Unit IE83-1 NONLINEAR DETECTION AND ESTIMATION

Principal Investigators: Professor S.I. Marcus (471-3265)
Professor J.L. Speyer (471-1356)

Graduate Students: Jessy Grizzle, Bih-Wan Lin, Taek Song, Evan Westwood and John White

A. OBJECTIVES AND PROGRESS: This research unit is concerned with several aspects of the statistical properties of nonlinear systems. Specifically, the design and analysis of optimal and suboptimal nonlinear estimators, the problem of detecting and identifying failure modes in fault tolerant systems, and the adaptive control and identification of queueing systems have been investigated.

1. Nonlinear Estimation

The nonlinear estimation problem involves the estimation of a signal or state process $x=\{x_t\}$ which cannot be observed directly. Information concerning x is obtained from observations of a related process $z=\{z_t\}$ (the observation process). The objective is the computation, for each t, of least squares estimates of functions of the signal x_t given the observation history $\{z_s, 0<s<t\}$ -- i.e., the computation of conditional expectations of the form $E[\phi(x_t) | z_s, 0<s<t]$, or perhaps even the computation of the entire conditional distribution of x_t given the observation history. These state estimates are generated by passing the measurements through a nonlinear system. Optimal state estimators have been derived for very general classes of nonlinear systems, but these are in general infinite dimensional. That is, it is usually not possible to recursively generate the conditional mean of the system state given the past observations. The basic objective here is the design, analysis, and implementation of high-performance optimal and suboptimal estimators which operate recursively in real time.

In a Lie algebraic approach to nonlinear filtering, we have studied the (Zakai) stochastic partial differential equation for an unnormalized conditional density $\rho(t,x)$ of the state x_t given the past observations $\{z_s, 0<s<t\}$:

$$d\rho(t,x) = L_0\rho(t,x)dt + L_1\rho(t,x)dz_t \quad (1)$$

where L_0 and L_1 are certain differential operators. The major idea of the approach is that, if $\mathscr{L}$ is the Lie algebra generated by $L_0 - \frac{1}{2} L_1$ and L_1, and if a recursive finite dimensional estimator for some statistic of the state exists, then there should be a Lie algebra homomorphism from $\mathscr{L}$ to the Lie algebra $\mathscr{F}$ of the finite dimensional filter. $\mathscr{F}$ is a Lie algebra of vector fields on a finite dimensional manifold, so the representability of $\mathscr{L}$ or quotients of $\mathscr{L}$ by vector fields on a finite dimensional manifold is closely related to the existence of finite dimensional recursive filters.

The cubic sensor problem (linear system with cubic observations) is considered in [1]. It is proved that neither $\mathscr{L}$ nor any quotient of $\mathscr{L}$ can be realized with C^∞ or analytical vector fields on a finite dimensional manifold, thus suggesting that for these problems, no statistic of the conditional density can be computed with a finite dimensional recursive filter. This result, together with analytical results, implies that for the cubic sensor problem, no nontrivial statistics can be computed recursively with finite dimensional filters; this is the first such result in the literature.

This result, however, does not address the issue of non-exact but high-performance suboptimal filters; this issue is addressed in [2]. In this paper, we have considered linear estimation problems with small nonlinear perturbations. A typical such system is of the form

$$\begin{aligned} dx_t &= ax_t + dw_t, \\ dz_t^\varepsilon &= [x_t + \varepsilon h(x_t)]dt + dv_t, \end{aligned} \tag{2}$$

where h is a polynomial function. In general, such problems do not possess finite dimensional filters for the conditional statistics, and approximate filters are sought. The approach is to expand the unnormalized conditional density $\rho(t,x)$ in powers of ε

$$\rho^\varepsilon(t,x) = \rho_0(t,x) + \varepsilon\rho_1(t,x) + \varepsilon^2\rho_2(t,x) + \dots \tag{3}$$

In order for this expansion to result in a useful suboptimal filter, we first showed that the error

$$\rho^\varepsilon(t,x) - \sum_{i=0}^{n}\varepsilon^i\rho_i(t,x) \tag{4}$$

is of the order of ε^{n+1} for ε small; i.e., (3) is a true asymptotic expansion. Then the same result was shown to be true for approximations of the normalized conditional density and conditional means.

Even if (3) is an asymptotic expansion, it is not of much use in nonlinear estimation unless each term in (2) can be computed with a finite dimensional recursive filter. It is in this phase of the investigation that Lie algebraic methods are useful, because they can provide guidance into the computation of such filters. In [2], it is shown that the individual terms in (3), and hence the conditional mean, can indeed be computed with finite dimensional filters. The mean-square errors of the resulting filters in the case of the zero-th and first order approximations were compared via Monte-Carlo simulation to the extended Kalman filter (EKF) and the Bobrovsky-Zakai lower bound. The behavior found in all the simulations was the following: the zero-th order filter performs worse than the EKF, but the first order filter performs better than the EKF (which is the most widely used suboptimal filter).

We attempted to utilize a similar approach to the estimation problem with infrequently jumping unknown parameters in [3]. A typical system of this type is given by

$$dx_t = a(\theta_t)x_t dt + b(\theta_t)dw_t$$
$$dz_t = c(\theta_t)x_t dt + r^{\frac{1}{2}}dv_t$$

where θ is a finite state Markov process taking values in $S=\{1,\ldots,N\}$,

and having probability vector $p_t=[p_t^1,\ldots,p_t^N]^T$, $p_t^i = P(x_t=i)$,

satisfying

$$\dot{p}_t = \varepsilon G^T p_t,$$

$\varepsilon>0$. The value of θ_t is called the "regime" at t. We desire to estimate x_t and θ_t given $\{z_s, 0\leq s\leq t\}$. If $\varepsilon = 0$ and the parameter θ is a constant random variable, a finite dimensional filter exists; we are interested in studying the problem for small ε, in which case the parameters are "jumping infrequently". Although this problem is similar to the one with polynomial nonlinearities discussed above, it is in fact much more difficult to apply a similar method of deriving filters. It can be shown that the error (4) is of the order of ε^{n+1}

for ε small; however, for all but the first term, it <u>cannot</u> be shown that the individual terms in the expansion (3) can be computed with finite dimensional filters, since infinite dimensional Lie algebras arise. Therefore, in [3] the zero-th order filter is compared via simulation to other filters, many of which perform better. It is concluded that the applicability and utility of these methods is highly problem-dependent.

A new globally convergent nonlinear observer, called the modified gain extended Kalman observer (MGEKO), has been developed for a special class of systems [4,5]. This special class of systems is composed of nonlinear modifiable functions $a(x_i)\varepsilon\mathbb{R}^q$ which can be represented as

$$a(x_i)\varepsilon\{f(x_i)\varepsilon\mathbb{R}^q: \ f(x_i)-f(\bar{x}_i)=g(z_i^*,\bar{x}_i)(x_i,\bar{x}_i) \text{ for all } x_i,\bar{x}_i\varepsilon\mathbb{R}^n\}$$

where $z^*=h(x)$ is the measurement function, $g(z_i^*,\bar{x}_i)$ is a qxn matrix and the subscript i denotes the stage time of the underlying process. If a system is composed of only this class of nonlinear functions, then the error in the estimate is propagated by a linear equation whose coefficients are composed of the function $g(z_i^*,\bar{x}_i)$. The globally convergent property of the associated nonlinear observer is found by using a quadratic Lyapunov function of the estimation errors.

If this observer is used in a noisy environment, then biased estimates result. This is because both the residual and the gain are functions of the present measurement and, therefore, are correlated. To avoid this effect, the algorithm is modified so that the gain is not a function of the present measurement. Although some reasonable but uncheckable assumptions are required, the filter, called the modified gain extended Kalman filter (MGEKF), is shown under certain side conditions to be exponentially bounded in mean square. This result is obtained by first constructing a nonrealizable but exponentially bounded filter used as the nominal from which the sufficiency condition for exponential boundedness of the MGEKF is obtained.

Although the class of modifiable functions is quite small, it does include two important engineering estimation problems: estimation with bearings-only measurements, and state estimation and parameter identification in linear systems. In [4] the bearings-only measurement problem is described; in this problem, the angle measurements are linear in a spherical coordinate frame and the dynamics are linear in a rectangular coordinate frame. Although the bearings-only measurement in two dimensions is modifiable in a rectangular coordinate frame, the vector bearings-only measurement is approximately modifiable in three dimensions. Nevertheless, simulations revealed stable and unbiased behavior in the noisy measurement case, thus showing superior performance with respect to existing filter mechanizations.

The application of the MGEKF to the state and parameter estimation problem requires a proper choice of state space. Unlike the bearings-only measurement problem, the dynamics of the system are nonlinear. Previous application of the EKF to this problem using a controllability canonical form produced inferior performance over other techniques like maximum likelihood estimators. In the controllability canonical form the nonlinearities are not modifiable [5]. By transforming into an observability canonical form, the nonlinearities are modifiable. The resulting performance of the MGEKF for a particular example [6] is as good as the best parameter estimator. By using the convergence analysis of [7], for a scalar example the convergence rate of the MGEKF has been shown to be faster than that of the filtered state EKF. The estimates of the state and parameters are unbiased for both filters when the process noise variance is known and slightly biased when off by a factor of ten.

The research in this area is continuing and has been complemented by contract F08635-82-C-0090 from the U.S. Air Force Armament Laboratory, Eglin Air Force Base, Grant AFOSR-79-0025 from the Air Force Office of Scientific Research, and Grant ECS-8022033 from the National Science Foundation.

2. Fault Detection and Identification

An essential aspect in the design of fault tolerant digital flight control systems is the design of failure detection and redundancy management systems. Design considerations are concerned with the trade-off between the cost of hardware redundancy and the complexity and robustness of the software for analytic redundancy. In analytic redundancy, dissimilar instruments are combined through analytic relations to achieve redundancy. Since these relations contain system parameters, additional uncertainty may be introduced beyond that present in the sensors. The processing of the outputs of these relations to produce adequate fault detection and isolation performances may require complex decision and estimation software. A decision rule, the Shiryayev sequential probability ratio test (SPRT), is used in [8] to detect failures between similar instruments, as well as between dissimilar instruments through analytic redundancy. Unlike the Wald SPRT, which tests for the presence of a failure or no failure in the entire data sequence, the Shiryayev SPRT detects the occurrence of a fault in the data sequence in minimum time if certain conditions are met. The performance of the Shiryayev SPRT in detecting a failure between two rate gyros as compared to standard fixed interval schemes is presented, as is the performance for a single accelerometer failure using translational kinematic equations to form a parity relation for analytic redundancy. The results of [8] have been extended to include the derivation of a relatively simple algorithm for testing multiple failure hypotheses against a single unfailed hypothesis.

Investigation of the respective structures of open-loop and closed-loop residual generating schemes has indicated that the basis of the system representation plays an important role. Specifically, the open-loop residual generation is naturally related to an observability form representation, while the closed-loop residual formation by the detection filters is simplified by the use of observer form dynamic systems [9].

3. Identification and Adaptive Control of Queues

Closely related to the parameter identification and fault identification problems discussed above are problems involving queueing systems with unknown parameters. In such problems, parameter identification algorithms are of interest; even more important is the on-line use of these algorithms in adaptive control algorithms. In [10], the problem of adaptively controlling the service rate in an M/G/1 queueing system in the presence of unknown parameters has been considered. This is a single-server system where customers arrive according to a Poisson process with parameter λ, and they are served in the order of their arrival (first-come, first-served). The arrival process is assumed to be independent of the service. At each service completion time the server must decide the service rate u with which the next customer will be served, where u can be any value in some compact interval $U = [\mu_0, \mu_1]$, $\mu_1 > \mu_0 > 0$. In such a case, the service time of the next customer is a random variable with distribution $G(\cdot, u)$ and mean value $m(u) = \int_0^\infty t dG(t,u)$. The state of the system at time t, denoted by $X(t)$, is the number of customers in the system. The decision points are the epochs at which a service is completed. Whenever the system is in state $x \varepsilon S$ and action (service rate) $u \varepsilon U$ is being used, a cost at rate $c(x,u) \geq 0$ is incurred. The problem is to determine a policy which minimizes the average cost given that the arrival rate is a constant but unknown parameter. An optimal adaptive policy is determined using recently developed results on parameter estimation and adaptive control of semi-Markov processes.

In related work, we have in [11] presented a distance-measures approach to the problems of identification and approximation of queueing systems. This approach combines ideas from statistical robustness, information-type measures and parameter-continuity of stochastic processes.

The research in this area is continuing and is complemented by Grant AFOSR 84-0084 from the Air Force Office of Scientific Research.

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Research Unit IE83-2 ELECTRONIC TIME-VARIANT SIGNAL PROCESSING

Principal Investigator: Professor J.K. Aggarwal (471-1369)

Graduate Students: T. Leou, N. Nandhakumar and S. Park

A. OBJECTIVES AND PROGRESS: The broad objective of this research unit is to develop new and efficient techniques for processing time-variant signals. Our recent research efforts have been directed toward the analysis, synthesis and implementation of linear time-variant (LTV) digital filters in time and frequency domains. Besides the exploration of the basic properties of LTV digital filters, we focus our attention on developing new synthesis structures which require less computation and storage and on minimizing the complexity of the synthesizing algorithms involved. The progress of this research unit is briefly stated as follows.

We have studied the interrelationships among the three common characterizations of LTV digital filters; the time-variant impulse response, the generalized transfer function and the time-variant difference equation [1]. In particular, we have shown that an impulse response is realizable as a time-variant difference equation if and only if it is expressed as a degenerate sequence. As documented in [2], we have developed a spectral modification technique which varies the filter characteristics according to the changing frequency contents of the desired sequence. By using the property of the impulse response of a time-variant difference equation, we have developed two synthesis techniques based on the least-squares approximation of a given impulse response as a degenerate sequence [3]. In the first technique, the approximation is formulated as a spectral decomposition of the impulse response. In order to reduce the number of filter coefficients stored, a nonlinear minimization procedure has been proposed to approximate the desired impulse response as a degenerate sequence represented in terms of a class of special functions with fewer parameters. In [4], we have developed a technique to implement a one-dimensional (1-D) LTV filter with a two-dimensional (2-D) LTI filter by appropriately mapping 1-D input/output sequences into 2-D sequences. The synthesis techniques developed for 2-D LTI filters are then applied to solve the 1-D LTV filter synthesis problem.

In [5], [6], we have highlighted the misconception of synthesizing a recursive LTV filter based on the idea of the frozen-time transfer function. A typical example of the recursive LTV filter has been selected to illustrate the difference between the desired and the synthesized transfer functions. We have also identified the special cases in which the frozen-time synthesis technique produces satisfactory results.

Continuing our research on the synthesis of a LTV filter as a LTV difference equation, we have proposed two efficient techniques which are applicable to the case where the desired filter characteristics can be approximated quite well using a finite-order LTV difference equation. As reported in [7], the synthesis problem can be formulated by assuming that the desired impulse response satisfies a LTV difference equation with a small error term added. Then the filter coefficients can be derived from a set of linear equations which are formulated by minimizing the error term in the least-squares sense. We have also investigated a technique for realizing a given rational generalized transfer function in terms of a LTV difference equation [8]. The coefficients of the LTV difference equation are related to the coefficients of the generalized transfer function by a set of overdetermined linear equations. The minimax solution of this over-determined set of linear equations has been shown to provide a good approximate realization of the generalized transfer function. The necessary conditions for the realization of a generalized transfer function can also be derived from this formulation. Both of these techniques have avoided the numerical difficulties in making the spectral decomposition of a large matrix and in calculating the solution of a nonlinear minimization.

Further, we have also investigated new synthesis structures in addition to the LTV difference equation. In [7], [9], LTV filters are synthesized as a parallel combination of a finite number of LTI filters each followed by a time-variant multiplier. The filter structure is further simplified by replacing the parallel combination of LTI filters with a cascade connection of recursive LTI filter sections.

The research on LTV digital filters is being continued. Now, we are investigating the basic properties of recursive LTV filters represented in the state variable form. The analysis of such LTV filters may be drastically simplified by using a time-variant state transformation which can diagonalize the state feedback matrices. Here, our objective is to develop a unified approach to the analysis and synthesis of LTV filters, regardless of the specific filter structure.

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THE UNIVERSITY OF TEXAS AT AUSTIN ELECTRONICS RESEARCH CENTER
INFORMATION ELECTRONICS

Research Unit IE83-3 DIGITAL TIME SERIES ANALYSIS WITH APPLICATIONS TO NONLINEAR WAVE PHENOMENA

Principal Investigator: Professor E.J. Powers (471-3954)

Research Associate: Dr. Jae Y. Hong

Graduate Students: DooWhan Choi and Taiho Koh

A. OBJECTIVE: The overall scientific objective of this research unit is to conceive and implement unique digital time series analysis techniques that may be used to analyze and interpret nonlinear wave fluctuation data in such a way as to provide new experimental and physical insight into a variety of important nonlinear wave phenomena. Our approach is multidisciplinary and rests upon synthesizing appropriate knowledge from the fields of nonlinear waves, nonlinear systems, and digital signal processing. Particular emphasis is placed upon modelling the linear and nonlinear relationships between two (or more) time series in the frequency domain via a hierarchy of linear and nonlinear transfer functions. Such transfer functions are closely related to physics in that the transfer functions are a measure of the "efficiency" with which various spectral components in the input mix to transfer energy to new spectral components in the output. We anticipate that the results of this research will continue to impact on many important scientific and technological problems, some of which are discussed in the next section.

B. PROGRESS: The majority of our earlier work dealing with bispectral analysis was limited to considering one channel of time series data at a time. The focus of our current research is concerned with considering two (or more) channels of wave fluctuation time series data and developing digital time series techniques that will enable one to identify any linear/nonlinear relationships between the two time series, and to model this relationship in terms of a hierarchy of linear and nonlinear transfer functions. Our progress in meeting this objective may be divided into the following three areas: (1) the theory of nonlinear systems modelling in the frequency domain, (2) computation of nonlinear transfer functions directly from the raw two-channel time series data via higher-order cross-spectra, and (3) validation of the approach in terms of application to real physical problems.

We have developed a conceptual nonlinear systems model in the frequency domain that corresponds to the Fourier transform of an orthogonalized Volterra functional series model in the time domain [1]. This model is valid for zero-mean Gaussian inputs with arbitrary spectral density. The model consists of a parallel combination of linear, quadratic, cubic, etc., transfer functions such that when the actual input is applied to the model, the model output approximates the output of the actual physical very well. In particular the concept of coherency has been extended to quantify the goodness of the model.

Of particular importance is the fact that the model indicates how the linear, quadratic, and cubic transfer functions may be estimated by computing the cross-power, cross-bispectrum, and cross-trispectrum, respectively, given the actual input and output time series data. Computer programs have been written to estimate such transfer functions. The validity of the model and the computer software have been validated by applying them to a variety of scientific and technological problems, some of which are described in the following paragraphs.

It is relatively well known that vessels moored in random seas can undergo large-amplitude low-frequency oscillations at or near the undamped natural frequency of the vessel-mooring system. Since such low-frequency excursions are significantly below the dominant frequencies associated with the incident sea waves, a nonlinear mechanism is at play. Indeed it can be shown that there is a weak second-order force that is proportional to the square of the incident wave height. As a result of this square law relation difference frequencies are generated, some of which lie within the resonant bandwidth of the vessel mooring system. Thus a relatively large amplitude response may result at the resonant frequency. In a paper [2] which was recently accepted for publication we indicate how digitally implemented cross-bispectral analysis techniques may be utilized to model the quadratically nonlinear response of moored vessels subject to random seas. The model consists of a linear and quadratic transfer function in parallel. The goodness of the model is quantified by comparing the actual power spectrum of the moored vessel response with that "predicted" by the model. As is indicated in the paper the agreement is quite good.

Another application involves electromagnetic scattering from nonlinear objects such as man-made metallic objects. It is well known that the I-V characteristics of the junctions associated with metallic joints often are nonlinear and are predominately cubic. In the past [3] we proposed a conceptual model which enables one to systematically characterize a nonlinear target in terms of a hierarchy of linear, quadratic, and cubic cross-sections. Such cross-sections are similar to the linear and nonlinear transfer functions used to model nonlinear systems and can be computed, using higher order spectral analysis techniques, from knowledge of the incident and scattered signals. In a recent conference paper [4] we investigated the ability of the cross-trispectrum to detect the presence of a weak third harmonic (generated by the cubic nonlinearity) when it is far below external noise or an intentional jamming signal. It was demonstrated that the cross-trispectrum can detect the third harmonic for $S/N \approx -20$db, this is a consequence of the fact that the cross-trispectrum is a sensitive measure of the phase coherence between the transmitted fundamental and weak backscattered third harmonic.

Another important application area involves investigating and quantifying spectral energy transfer associated with nonlinear mode interactions in structures. In refs. [5] and [6] we report on the use of auto- and cross-bispectral analysis techniques to identify autoparametric mode generation and nonlinear mode interactions.

In a project supported principally by the National Science Foundation, measurements of nonlinear interactions occurring during transition to turbulence of a symmetric wake have been studied using digital higher-order spectral analysis techniques developed under JSEP auspices. In a recent paper [7] it was shown how digital bispectral analysis measurements may be used to quantitatively study the features of nonlinear wave interactions which govern the energy redistribution and randomization processes during transition to turbulence.

Although the principal thrust of this research has focused on quantifying nonlinear wave phenomena in the frequency domain we have carried out some initial work in the time domain as well. This approach [8] considers a class of nonlinear filters with Volterra series structures under the assumption that the filter inputs are Gaussian. Under this latter case a simple solution results which is directly applicable in many practical applications. In fact the resulting second-order Volterra filter has been shown [9] to predict in time the nonlinear low-frequency response of a moored-vessel in random seas.

C. FOLLOW-UP: We will continue our work on developing digital time series analysis techniques to investigate nonlinear wave interactions in a variety of physical media. In addition to following-up the second-order quadratic Volterra (time domain) filter mentioned in the previous section, we plan to extend the frequency domain nonlinear transfer function work to direct measurements of three-wave coupling coefficients in turbulent media.

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II. SOLID STATE ELECTRONICS

THE UNIVERSITY OF TEXAS AT AUSTIN — ELECTRONICS RESEARCH CENTER
SOLID STATE ELECTRONICS

Research Unit SSE83-1 Solid State Interface Reactions and Instabilities

Principal Investigators: Professor R.W. Bene (471-1225)
Professor R.M. Walser (471-5733)

Graduate Students: Chien-Hwei Chen and Hwa-Yueh Yang

A. RESEARCH OBJECTIVES: The common research objective of the work reported in this unit is to gain a detailed understanding of the kinetic selectivity of the condensed phase. We are concerned with the study of how materials are destabilized by non-equilibrium or far-from-equilibrium excitation and the relationships between the excitation and the selection of unstable and metastable states available to them. In practice the excitation is generally supplied by a directed radiation or particle flux, such as a laser or ion beam, or possibly by high local thermal gradients as in a quenching experiment. The destabilization of the condensed phase is clearly favored, therefore, in lower dimensionality. Uniform, intense, directed radiation and particle beam excitation, for example, will frequently select $\sim$2D non-equilibrium states, as in, for example, the nucleation of surface compounds by laser beams. It is also evident that such low-dimensional non-equilibrium processes will be especially favored at surfaces and interfaces.

The distinguishing feature of kinetic selectivity is the observation that the excited state is relaxed by a metastable, or possibly, unstable state. A good example of this is in silicide formation where, according to our model [1-2], the surface excited states produced by deposition are relaxed, initially by the formation of a $\sim$2D glassy state, and eventually through the formation of a silicide when this glassy layer is destabilized. The process kinetically selects a silicide which is invariably not the equilibrium phase in the system. Of course, it is possible that the specific kinetics of the process fortuitously correspond to equilibrium, or energetic, selectivity.

The reaction kinetics of such processes can, in some cases, be resolved by utilizing short pulse laser diagnostics. Previous work in this unit described the use of picosecond pulse excite and probe techniques to explore metastable state selectivity at a prototype solid-solid phase transition, i.e., at the martensitic phase transition of VO_2 [3,4]. More recently similar techniques have been applied to the study of laser damage in crystalline silicon [5-12]. This research demonstrated, for the first time, that laser damage is a non-equilibrium phase transition and can be studied by the methods used to explore similar critical phenomena. At present, this work has been greatly expanded and is now being pursued separately under research unit QE83-1.

Kinetic selectivity is of extreme importance in microelectronics processing where virtually every interface in, for example, a silicon integrated circuit, is not at equilibrium. The electronic properties of the $\sim$2D metastable states at the interfaces dominate the performance of ohmic contacts, Schottky barriers, FET's, etc. In addition, the thermodynamic proximity of these states to other metastable or stable states is the origin of most reliability problems in microelectronics.

Here we report progress in two such studies. Both are concerned with understanding the overall systematics of solid state reactions. This understanding involves both the microscopics and macroscopics of the nature of interfaces and their evolution to a nucleation transition.

The specific objectives of the first study is to develop a set of rules for predicting the first nucleation product in solid state reactions and to measure properties of the interface region undergoing the evolution to first nucleation. The properties measured are structure and topology using transmission electron microscopy and diffraction (TEM/TED), stress, surface resistance, noise, dielectric response, and magnetic properties. The interfacial systems under study are those between semiconductor substrates (Si, GaAs, CdTe, $Hg_xCd_{1-x}Te$) and metals (Cu, Co, Ni, Ti, Pd, Pt, V, etc.).

The objective of the second study is to develop an in-situ technique for monitoring the dynamic precursors to interface instabilities in solid phase epitaxial growth (SPEG). These experiments have been started only recently and will focus on the systematic experimental study of intrinsic and impurity-assisted interface instabilities in the SPEG of ion implanted semiconductors. Our initial work will be with self-ion amorphized silicon implanted with hydrogenic (B,P, etc) impurities. In the initial phase of this work we will attempt to systematically characterize the effect of impurity concentration and temperature of SPEG kinetics with greater precision than previous studies. All previous work has utilized post-anneal analysis, with, for example, BSS (backscattering spectrometry); of isochronally annealed samples. The analysis of the results of these experiments rely on inadequate and fairly inaccurate data. The experimental techniques used are incompatible with the type of in-situ observations necessary to study the dynamics of the interface close to the onset of a SPEG instability.

Accordingly, we have constructed a high temperature, vacuum furnace compatible with the insitu study of SPEG dynamics by laser techniques. Laser interferometry will be used initially to determine, with precision, the boundary of the impurity induced SPEG instability. In subsequent experiments we plan to investigate the density fluctuations of this region using light scattering techniques. The results of these experiments are expected to contribute to the development of experimental techniques to (1) eliminate, or reduce, anneal-generated defects in ion-implanted semiconductors, and (2) synthesize electronically-useful metastable alloys and microstructures by ion implantation.

B. PROGRESS: We have successfully developed rules for 1st nucleation in metal on Si, Ge and metal on metal binary systems. We have seen in these systems that nucleation is dominated by internal kinetics as indicated by phase proximity to low temperature eutectics in the binary phase diagram. We are in the process of defining the extra important considerations when we deal in ternary or higher systems such as encountered with metals on binary semiconductors or alloys of 2 metals on Si and Ge. It has become clear in our initial measurements of Pd on GaAs and Cu and Co on CdTe and $Hg_{.8}Cd_{.2}Te$ that in the prediction of reaction kinetics the energetics of the reaction need to be taken into account - perhaps by using "modified" forms of the binary phase diagrams. In addition, the role of oxygen in promoting surface reactions which would appear to be nonreactive is evidently extremely important in evaluating experiments which have been done and are in the literature data base.

We are thus in the process of making (TED/TEM) measurements of the following ternary and higher ultrathin film systems in an effort to get some key unambiguous information about ternary systems.

1) Ti - Ni on Si
2) Ti - Co on Si
3) Al - Ti on Si
4) Pd on GaAs
5) Cu, Co, In on CdTe and $Hg_{1-x}Cd_xTe$

We have also made a series of measurements of other properties on metal-Si systems in the prenucleation regime in an effort to learn more about the microscopic evolution of the interface leading to crystallization.

We have seen in the Co-Si (and other) systems that the thin noncrystalline film goes through a semiconductor-metal transition just preceeding the onset of 1st nucleation [13]. This is an indication that the crystallization transition is driven by the macroscopic electronic state. In this same system we have measured the excess "1/f" noise and seen a gradual rise in noise magnitude of over 5 orders of magnitude as crystallization is approached and then a rapid drop of ~6 orders upon crystallization. Also in this system the frequency exponent varies from near 1 to near 2, then abruptly back to 1 [14]. (This work on noise is supported by NSF.) We have also completed initial measurements on stress development in thin Co films on Si in order to test the sensitivity of the measurement technique for films of thickness on the order of 10-20A and greater. We have been successful in thinning the Si down sufficiently that we can see the changes in stress for 20A of Co under different annealing conditions - and can easily see the onset of crystallization of first, (Co_2Si), second (CoSi) and third ($CoSi_2$) phase formation indicated in the stress changes [15].

In addition we have made considerable progress in initiating our study of SPEG instabilities in silicon. Considerable effort has gone into the procurement, installation, and checkout of our newly acquired VEECO-AI 400 KeV research ion implanter. This instrument will be used to fabricate the self-ion amorphized silicon SPEG substrates and to make the subsequent impurity implants. we have also constructed the induction heated, high temperature (to $\sim 800^0$C) vacuum SPEG furnace. In this system, the SPEG regrowth occurs inside a graphite susceptor whose temperature is continuously adjusted and monitored with $\sim$0.1% accuracy. The furnace and susceptor are equipped with optical windows for laser interferometric determination of the SPEG kinetics.

We have also constructed the CW laser (HeNe) laser interferometer to be used in the study. This system has been tested experimentally and is presently being calibrated. We have also made computer simulations of the SPEG regrowth and completed an error analysis to determine the expected accuracy of activation energies measured by laser interferometry.

The SPEG implants have been designed and a series of samples for the first measurements will be made in about one month.

C. FOLLOW-UP: We are continuing in our TED/TEM measurements of metals on binary and ternary semiconductors and also on the binary metal-silicon systems. We are using these results as they become available as well as the results of our colleagues in other laboratories in our continuing effort at demonstrating the overall systematics of solid state reactions by developing rules, which one can predict 1st nuclcation products at interfaces.

We are also continuing in our efforts at probing the evolution of properties of interfaces in the prenucleation regime, particularly for stress in ultrathin films. We are in the process of making in-situ measurements of interface stress for films of Co deposited on Si under different conditions (of substrate and ambient).

In addition we plan to begin measurements on Ti-Si and Ti-GaAs systems.

In the next period we will also make systematic experimental determinations of the critical concentrations of hydrogenic impurities at the onset of SPEG instabilities in silicon. These instabilities are associated experimentally with micro-alloying and impurity clustering, and occurs when the interface regrowth velocity drops below a critical value. The regrowth velocity can be controlled independent of temperature by varying the impurity concentration which, for implanted layers, varies with the implant dose.

We also plan to develop transverse (to the interface) cross section TED/TEM microscopy to investigate the morphology and clustering that occurs at the impurity induced SPEG instability. The results of these experiments will be a first step at determining the range of experimental parameters appropriate for the study of dynamical light scattering from the interface.

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THE UNIVERSITY OF TEXAS AT AUSTIN ELECTRONICS RESEARCH CENTER
SOLID STATE ELECTRONICS

Research Unit SSE83-2 ELECTRONIC PROPERTIES AND STRUCTURE OF METAL SILICIDES AND INTERFACES

Principal Investigator: Professor J.L. Erskine (471-1464)

Graduate Student: Joe Comunale

A. OBJECTIVES: The scientific objective of this research unit is to investigate the structure and electronic properties associated with selected solid surfaces and solid state interfaces. The work involves several related subareas: 1) metal/semiconductor interfaces, 2) metal and semiconductor surface/adsorbate systems, 3) metal and semiconductor surface reconstruction.

Research on metal/semiconductor interfaces is focused on understanding the electronic structure and composition of silicide structures which form when metal atoms deposited on a semiconductor surface react to form an interface. Particular emphasis is being directed towards understanding structural, metallurgical and electronic properties of the silicide interfaces which affect selective growth processes and electrical characteristics, namely the Schottky barrier height. This work utilizes Auger electron spectroscopy (AES), to characterize near surface composition, low energy electron diffraction (LEED) to determine geometrical structure, angle resolved photoelectron emission spectroscopy (ARPS) to study electronic properties of the constituent atoms and transmission electron diffraction (TED) to study interface crystal structure and composition.

Research on surface/adsorbate systems is primarily oriented towards supporting our work on metal/semiconductor interfaces. In preparing any solid state interface, impurity atoms and molecules are incorporated from the background of atomic and molecular species in the vacuum chamber. These impurities can chemisorb at surfaces where interfaces are being formed and can influence the growth kinetics, electronic properties and crystal structure of the interface. Recent experimental work on the initial stage of silicide growth in the Pd silicide and Ni silicide systems has suggested that surface reconstruction (which is affected by adsorbates) can play a significant role in the nucleation of templates which control interface crystal structure.

Several state-of-the-art experimental techniques are available to accomplish this work. These include high-resolution electron energy loss spectroscopy (EELS) which permits studies of surface vibrational properties and several synchrotron radiation based spectroscopic techniques.

B. PROGRESS: We have made significant progress in several subareas indicated in Section A which summarizes our objectives. This section outlines scientific progress in these subareas and describes current efforts to obtain new instrumentation required for our proposed research.

1. Metal Semiconductor Interface

We have studied the low coverage interaction of Ni atoms with Si(100) surfaces and have reported that it is possible to form a diffusion layer of Ni atoms in the Si lattice with novel properties [1]. We believe that the diffusion layer is characterized by Ni atoms in interstitial voids of the Si lattice, and that these Ni interstitial defects can account for selective growth processes based on a model proposed by Tu [2]. The diffusion layer is not depleted by prolonged annealing, and the stoichiometry of the layer is $NiSi_2$. Several other groups are now studying this system using LEED [3], surface EXAFS [4] and TEM [5]. These groups also find a $NiSi_2$ stoichiometry interface, but believe that the crystal structure is the CaF_2 structure of $NiSi_2$ rather than our proposed diffusion layer structure [6]. The most important result, however, is that there appears to be a silicon rich compound at all practical interfaces formed as a result of the interaction of nickel films at silicon surfaces.

Our photoemission studies have established that a Si rich silicide is always present during the initial phase of interface formation. This phase can be identified along with the polycrystalline stoichiometric phases which nucleate and grow by selective growth at various temperatures (Ni_2Si at 200°C and NiSi at 430°C). Our transmission electron diffraction studies have shown that the silicon rich phase is ordered and corresponds to an fcc superlattice of Ni atoms. This result has important implications [6]. First, it provides a basis for accounting for the constant Schottky barrier height in Ni silicide interfaces independent of the silicide phase which forms the "metal" contact. Second, it suggests that either the interface phase can bypass selective growth to form $NiSi_2$ or that the diffusion layer (which has the same stoichiometry but different crystal structure) forms. If the actual structure is the diffusion layer structure as we have suggested, then this result can account for selective growth. Escape depths at photon energies we have been able to use are not quite sufficient to obtain reliable interface information, and we plan to conduct x-ray photoelectron measurements on these systems when we obtain the necessary instrumentation.

2. Rare Gas Atoms on Surfaces

Recent experimental [7] and theoretical [8] results suggest that the binding energy of electronic states associated with rare-gas atoms on surfaces exhibit important features which are related to the work function appropriate to microscopically small regions of a substrate. The chemical activity associated with small regions such as steps and corners, and the site specific nucleation of phases during metal deposition on semiconductor surfaces makes the determination of the local workfunction potentially very important. We are beginning a comprehensive study of these effects using several model systems. Progress to date includes improvements in the differential pumping of our resonance lamp which permits photoemission experiments to be conducted with the sample maintained at low temperature (30-40^{0}K), and improvements in the target manipulator which allow it to reach the low temperatures required to physisorb Xe, Kr and Ar gas.

3. New Instrumentation

We have received funding from the National Science Foundation (Division of Materials Research) to set up monochromators and beam lines at the Synchrotron Radiation Facility in Stoughton, Wisconsin. The joint project involves The University of Texas at Austin, Cornell University, and Sandia National Labs and provides support to establish two beam lines at the Aladdin storage ring facility. The beam lines will consist of a 6-meter toroidal grating monochromator (photon energy 10-200 eV) and an extended range grasshopper monochromator (photon range 20-1500 eV). This instrumentation will increase tremendously the range of materials science research we are able to conduct through our JSEP center.

Local high resolution x-ray photoelectron spectroscopy facilities are needed to conduct some of our planned experiments, and requested DoD instrument program funding would make it possible to pursue these experiments on campus.

C. CURRENT RESEARCH: We are having to change our research plans for the near future. Most of our proposed interface work was based on the reasonable assumption that we would be able to obtain some equipment funds, either through JSEP or through the DoD equipment program, to conduct x-ray photoelectron spectroscopy. Most of our photoemission equipment is being sent to Wisconsin to support NSF funded projects and we are now faced with choosing JSEP projects which can be carried out on remaining available equipment. We will continue our efforts to obtain some DoD support for instrumentation that can be used for interface spectroscopy, namely an XPS instrument. In the meantime, we plan to begin pilot experiments using high-resolution electron energy loss spectroscopy (EELS) to investigate vibrational properties of reconstructed surfaces. We have recently shown that EELS can be used to map the surface phonon bands of oxygen on Ni(100) [9]. The vibrational properties of surfaces are closely related to structure [10].

Lattice dynamical calculations permit structural models to be tested against vibrational data, and we have the ability to perform these calculations [10]. If we can obtain direct line access to the new JSEP VAX computer, we will begin lattice dynamical calculations for reconstructed Si(111) and (100) surfaces and EELS measurements of these surfaces to obtain new insight into the surface structure.

We also plan to continue our work on local work function determination using photoelectron emission from rare gas atoms on selected surfaces. Again, an x-ray source will be needed to finish this work. We can excite the $5P_{3/2}$ and $5P_{1/2}$ levels of Xe, but not the 4d core states. It is important to be able to probe both 4d and 5p states. The spatial extent of the 5p states is a factor of 5 greater than the 4d states, and the binding energy shifts associated with local work functions depend on the initial-state wavefunction being located outside of the surface potential (the dipole-layer and exchange correlation components of the potential have different spatial properties). Our present experiments are being conducted on an ordered NiAl(110) crystal. The work function change from Ni to Al is over 1 eV, and this crystal appears to offer attractive possibilities for investigating potential applications of this technique to local work function determinations.

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THE UNIVERSITY OF TEXAS AT AUSTIN — ELECTRONICS RESEARCH CENTER, SOLID STATE ELECTRONICS

Research Unit SSE83-3 IMPLANTATION AND INTERFACE PROPERTIES OF InP AND RELATED COMPOUNDS

Principal Investigator: Professor Ben G. Streetman (471-1754)

Graduate Students: C. Farley, T. Kim, and H. Shin

A. SCIENTIFIC OBJECTIVES: Several important materials properties of InP make it particularly attractive for use in high-speed field effect transistors and integrated circuits, as well as in optoelectronic systems. In terms of electron mobility and peak velocity, this material competes well with Si or GaAs. Furthermore, InP appears to be a much better material than GaAs for metal-insulator-semiconductor (MIS) field-effect transistors (FETs). However, these inherent advantages cannot be exploited in electronic devices and systems without considerable basic understanding of effects occurring during processing. This information is currently unavailable or is too incomplete to be useful in device fabrication. The objective of this research is to provide better understanding of two of the most important of these effects: (a) impurity migration and activation during various implantation and annealing procedures; and (b) formation of a clean InP-insulator interface with an acceptable density of interface states.

In the implantation and annealing studies, our objective is to develop procedures for obtaining controllable profiles of implanted donors and acceptors with good electrical activation. Since previous work has shown considerable migration of impurities during typical thermal annealing of implanted InP, we expect some form of transient annealing will be required. This study will include work on proper encapsulation of the InP surface during annealing. Impurity distributions will be studied, along with donor or acceptor activations and interactions with background compensating impurities in semi-insulating InP material.

Surface studies will be concentrated on silicon nitride and germanium nitride layers on clean InP surfaces. The objective of this work is to develop a low interface state density, suitable for MIS device fabrication. Much of the effort will be devoted to development of oxygen-free Si_3N_4 and Ge_3N_4 plasma-enhanced deposition techniques. The system must also include facilities for removing the native oxide layer before nitride deposition.

A final objective of this work is to employ the results learned in the proposed fundamental studies to fabricate InP MIS transistor test structures. This portion of the work will be done in collaboration with colleagues at industrial and government laboratories.

B. PROGRESS: In order to support our investigations into the problems of implantation in InP, we have in the past year developed a full complement of experimental facilities including photolithography, ion implantation, annealing, impurity profiling, encapsulation and low temperature photoluminescence measurements.

As a tool for directing our work on impurity migration and activation, we have developed several computer simulation programs to account for effects of impurity concentration and damage in the redistribution of implanted impurities. This work was motivated by the desire to explain the anomalous diffusion of implanted Be and Mg during thermal annealing which has been reported by Oberstar et al. [1,2] and Vaidyanathan et al. [3]. SIMS profiles of annealed Be implants into InP showed that for high implant doses, the diffusion front penetrated less as the anneal temperature increased. Diffusion simulation is accomplished with a Crank-Nicholson [4] transformation of Fick's second law which has been reported elsewhere [5]. The general form of the model for the diffusion coefficient was suggested by the qualitative resemblance of the profiles reported by Oberstar to those of other acceptors implanted in GaAs and InP [6,7,8].

Using these simulations, we have developed a model for the diffusion coefficient of Be in InP [9], which gives results similar to those observed by Oberstar for Be-implanted InP. The resulting profiles suggest that Be and Mg may diffuse by an interstitial mechanism in InP and demonstrate that diffusion at and near the peak of the profile is a critical determinant of the final distribution. It appears that the depletion of Fe and Cr in the regions of fast Be diffusion is related to solid solubility, and it is believed that the presence of Fe and Cr on the In sublattice contributes to the concentration-dependent diffusion. This would explain why the effect was seen in compensated semi-insulating substrates and not in VPE material.

In addition to its application in the specific InP:Be problem, this model can be used as an analytical/predictive tool for estimating impurity migration of multiple implants. Once the diffusion coefficient is found for a single implant, the impurity profiles resulting from annealing multiple implants can be approximated.

In order to use ion implantation as a doping technology at and near interfaces of structurally or chemically dissimilar materials, it has become necessary to simulate the stopping of ions in a more exact manner than can be done by conventional LSS calculations. We have chosen to implement the Boltzmann transport equation as a means of calculating the momentum and energy transfers which an energetic ion undergoes as it comes to rest in a solid. An advantage of this method is that it allows calculation of the final implant particle distribution as well as the amount of damage created, the number of vacancies and interstitials created, and the net overall perturbations in lattice stoichiometry. This should be an extremely useful tool for analyzing the effect of lattice stoichiometry on migration and for investigations of implantation at interfaces, especially heterostructures. At present, the simulations are being implemented for bulk and single interface targets; further development will make these calculations available for an arbitrarily complex substrate.

To measure the profiles of free carrier concentration in implanted layers, we have implemented an AC Hall profiling system similar to the one developed previously by Streetman and his students at the University of Illinois. However, several design improvements allow a much higher signal to noise ratio to be achieved and permit measurement of very low carrier concentrations.

Work on the InP/insulator interface has centered on development of deposition systems for these insulators. We have constructed and are now operating a system for the deposition of phosphosilicate glass by CVD. We have also built and are operating a PECVD reactor capable of growing Si_3N_4 layers with no appreciable oxygen content (<1 atomic percent as determined from Auger spectra). We are in the process of designing and constructing a Ge_3N_4 CVD reactor in cooperation with K.P. Pande at Bendix Advanced Technology Center. These systems will allow us to begin assessment of various InP/insulator interfaces during the next reporting period.

C. FOLLOW-UP STATEMENT: The work described above is part of a continuing three year program for which this is the first annual report. Work in impurity migration and activation will proceed with the development of a thermal pulse annealing system using an incoherent light source. Atomic profiles of impurity distributions obtained from SIMS will be compared with electrical profiles obtained from Hall and C-V measurements. Work on the InP/insulator interface will center on surface cleaning and various deposition methods for the reduction of interface states at these novel interfaces.

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III. QUANTUM ELECTRONICS

THE UNIVERSITY OF TEXAS AT AUSTIN ELECTRONICS RESEARCH CENTER
QUANTUM ELECTRONICS

Research Unit QE83-1 QUANTUM EFFECTS IN LASER INDUCED DAMAGE

Principal Investigators: Professor M.F. Becker (471-3628)
Professor R.M. Walser (471-5733)

Graduate Students: Yong Jee and Yoon Kyoo Jhee

A. RESEARCH OBJECTIVE: The major objective of this research unit is to study the mechanisms of laser induced surface damage in solids. This year, emphasis was placed on silicon and metal surfaces. Our viewpoint is that laser induced damage is a first order phase transition; and, when it is induced by short laser pulses, it is non-equilibrium in nature. Experimental techniques which probe the state of the target materials near the damage threshold will be used to determine the characteristics of precursors to the phase transition or of accumulated states prior to damage. The study of charge emission and optical and electron micrographs of the damage morphology will augment statistical studies of damage in order to determine the nature of the accumulated states and the first detectable phase after damage has been nucleated. The long range goal of this research is to gain a detailed understanding of the process of laser induced damage leading to the effective design of damage resistant optical components.

B. PROGRESS: Two sub-areas of study in this research unit showed progress in the past year. The first is a nearly complete study of the charge emission and damage behavior of single crystal silicon irradiated below the single pulse damage threshold. The second is a newly initiated study of the multipulse damage behavior of several single crystal metals (Cu, Al, Ni, and Mo) at 1064 nm.

The study of the damage to single crystal silicon by 60 psec laser pulses at 1064 nm represents the results of several years work, publications [1-3], and a Ph.D. dissertation. The most recent findings pertain to the incubation or accumulation period before damage is first initiated in N-on-1 experiments and the subsequent charge emission and damage morphology development. The investigation of the incubation period was conducted by observing the first charge emission event for a sample in vacuum. It had previously been found that charge emission was always coincident with the first visible surface damage on silicon. Charge emission, both negative and positive, is a reliable indication that the incubation period has ended. In experiments, we measured the duration of the incubation period as a function of laser fluence and pulse repetition frequency (PRF). The dependence of incubation time on laser fluence was generally inverse and could best be fit by:

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$$N = N_o \exp((U_o - gE_1)/k'E_1) \qquad (1)$$

where E_1 is the laser pulse energy (or fluence), N is the number of pulses required to initiate damage (duration of the incubation period x PRF), and N_o, g, k', and U_o are material constants. The quantity $U_o - gE_1$ may be thought of as an activation energy for damage. This same empirical behavior is seen in the fatigue of solids subject to repeated stress. When PRF is a parameter, no change is observed in the incubation duration versus fluence curves over the range of PRFs from 1/3 Hz to 12 Hz. Thus, the accumulated specie is either permanent, or has a lifetime in excess of 10 seconds. Thermal modeling has eliminated heat as a quantity to be accumulated in these experiments. The cumulative temperature rise at these PRFs is negligible.

For laser fluences in the range where incubation is observed, we also measured the nonlinear absorption behavior of the silicon samples. A very strong quadratic dependence of absorption on fluence was observed. This indicates either a two quantum absorption or free carrier absorption. Subsequent modelling using the known free carrier absorption cross section shows that the nonlinear absorption in this case is almost entirely free carrier in nature. Nothing is observed in the absorption experiments that would indicate unusual accumulation or incubation behavior.

After the first damage was initiated, the charge emission and damage morphology development were studied. The morphology development had been investigated in a previous study and was correlated with the new measurements of charge emission. The quantity of emitted charge was measured as a function of laser influence and PRF. The charge emission of the first damaging pulse was very noisy, presumably due to site to site and statistical fluctuations. Averaging over the first several emission events gave more repeatable results which showed a monotonically increasing charge flux versus laser fluence. Although the dependence resembled a fifth power law, it is difficult to formulate a plausible theory which would generate such behavior for the emission of positive and negative ions and many-atom droplets of material. A more satisfying fit to the data was obtained from the Arrhenius relation, where laser energy, E_1 is substituted for temperature. The quantity of charge emitted fit the following relation:

$$N = N_o \exp(-U_o/E_1), \qquad (2)$$

This relationship indicates thermal evaporation of particles over an energy barrier, U_o, some of which are ionized and detected by the charge collector. Again, when the PRF dependence of this effect was studied, no change was found over a range of PRFs from 1/10 Hz to 13 Hz. A very long lived state or a permanent change is again suggested.

A third part of this study examined the emission behavior after the initial damage period. After incubation, the charge emission was found to increase rapidly with more pulses. This coincided with the damage pattern spreading to form the characteristic rows of pit chains throughout the entire laser beam spot. After a longer period of time, generally after 1000 pulses or more, the emission decreased somewhat and reached a fairly constant value. The morphology showed a reduction in pit density and a final quasi-stationary form where each pulse initiated evaporation from a relatively stable pit pattern and redeposition on the surrounding area. In general, charge emission seems to be proportional to the number of pits in the beam spot. An electrostatic calculation shows strong electric field enhancement at such surface structures, further supporting the conclusion that they are the principal source of charge emission.

A paper on these results has been submitted to the Journal of the Optical Society of America: Part B.

The experimental work on the single crystal metal samples has moved from the surface preparation and characterization stage into the first damage experiment stage. We are using three techniques for surface preparation, standard metallographic polishing, electropolishing, and single point diamond turning (by an outside vendor). Electropolishing is the only one of the three techniques that leaves the surface in a single crystal state as measured by X-ray techniques. Still under consideration is the ion beam milling of a diamond turned surface to remove the layer of surface disruption to the crystal lattice.

Initial damage experiments on mechanically polished and electropolished copper have been done using Q-switched pulses 23 nsec long at 1064 nm. Thresholds for 1-on-1 and N-on-1 experiments have been determined and an accumulation effect or fatigue limit behavior is clearly observable. Damage morphology for smaller numbers of pulses is in the form of melt pits, generally several microns in diameter. For a thousand or more pulses, the damage morphology appears to be smoother surface erosion ridges or possible slip bands in a generally circular pattern matching the beam spot. No periodic ripple formation has been observed unlike the silicon and aluminum samples.

C. <u>FOLLOW-UP:</u> The work in this research unit will continue. The question of what is accumulating in silicon remains to be answered. Work with other semiconductors may help with its understanding. The work with metal samples should begin to produce major results in the coming year. Another aspect of laser damage, charge sensitive diagnostics of accumulation and damage, is being pursued under AFOSR/SCEEE sponsorship in cooperation with the Air Force Weapons Laboratory.

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THE UNIVERSITY OF TEXAS AT AUSTIN ELECTRONICS RESEARCH CENTER
QUANTUM ELECTRONICS

Research Unit QE83-2 NONLINEAR RAMAN SCATTERING FROM MOLECULAR IONS

Principal Investigator: Professor J.W. Keto (471-4151)

Graduate Students: Norbert Boewering and John Sample

A. RESEARCH OBJECTIVES: The primary objective of this research unit is the development of coherent antistokes Raman scattering (CARS) or stimulated Raman gain spectroscopy for studies of reactions and structure of cluster ions formed at high pressures.

Research on the reactions and structure of ions at pressures near or above atmosphere is relatively new. Such studies have been motivated by electron beam driven or preionized lasers [1,2], particle beam weapons [3] and plasma chemistry [4]. To date most studies of ion-molecule reactions and recombination of positive ions with electrons or negative ions have been done at pressures up to 10 Torr. In part the restriction to low pressures has been intentional as the desire has been to understand the quantum mechanics for the interaction of two free particles. In general it is thought that when fundamental two-body interactions are understood, they can be used to model the more complicated systems.

Three-body collisions are known to be required in association reactions

$$A + B + X \rightarrow AB + X \tag{1}$$

where the third body relaxes the pair into a stable state by carrying away extra kinetic energy. In estimating the formation rates of cluster ions, Smirnov [5] has described several models for estimating three-body (termolecular) reaction rates. Though the importance of termolecular reactions for association of particles has long been known, it remains common for workers to assume that if bimolecular reactions are dominant at lower pressures that they continue to dominate at higher pressures. Hence dissociative recombination rates or charge transfer rates measured at low pressures are applied to models of discharges at higher pressures.

In previous units studying molecular reactions, we were motivated to understand the chemistry or excimer lasers; and in those studies found that both charge transfer [6] and recombination [7] was termolecular. However, our studies of ion-molecule reactions at high pressures were greatly hampered by the lack of a probe which can distinguish the ion type. For unambiguous studies it is necessary first to develop a selective probe applicable in high pressure discharges.

The probes for such studies must have high sensitivity, and good spectral and temporal resolution. Temporal resolution is required so that the decay rates can be used to measure reaction rates. We are interested in reactions such as association, recombination, and charge transfer. Nonlinear optical probes based on coherent Raman scattering processes when used in conjunction with high power pulsed lasers potentially meet all these criteria. Two techniques currently under consideration are coherent antistokes resonant Raman spectroscopy and gain modulated Raman spectroscopy. The spectral and temporal characteristics of these techniques are governed by the characteristics of the lasers employed. A major objective of this research unit is to demonstrate experimentally that such probes have the necessary sensitivity to detect molecular ions. When successful, these experiments will obtain the first Raman spectra of molecular ions and will greatly aid in the understanding of polyatomic molecules and high pressure discharges.

Polyatomic ions of interest include Xe_3^+, Ar_3^+ and Xe_nCl^+ which are relevant to excimer lasers. Other molecular ions for which there exists a need for experimental analysis include those formed in atmospheric discharges; H_3^+, N_3^+, N_4^+, O_3^+ and O_4^+ all fall into this category. The results from such studies will be applicable to the problem of particle beam transport in the atmosphere. Of particular fundamental interest is H_3^+ which is the simplest nonlinear polyatomic molecule. Data gathered on it may be compared directly to ab initio calculations [8].

B. PROGRESS: In nonlinear Raman spectroscopy, two lasers - often named the pump and probe laser - are focussed either colinearly or counter propagating onto a gas target. The third order susceptibility induced by the pump laser produces gain of the probe laser. In CARS, two waves from the pump beam combine with the probe to generate gain at the antistokes frequency. Both techniques have sufficient sensitivity to observe scattering from ion densities of 10^{14} cm^{-3}; but experimentally require all aspects to be optimized.

For CARS, a primary loss of signal occurs in separating the signal from the pump and probe lasers. We have designed a prism monochromator to separate the beams with 94% throughput for Raman energies as low as 25 cm^{-1}. The design was tested with a ray tracing computer program which computed losses through the system by reflection, scattering, and absorption. The device has been constructed and initial testing is now complete. These tests proved the general design, but showed that the purchased prisms failed to meet bid specifications. They have been returned to the factory to be reground.

While waiting for the completion of the prism monochromator, we have concentrated most efforts on SRGS. Previous experiments by Owyoung [9] used a quasi-c.w. laser as the probe laser. Gain was induced by a 10 nsec, high power laser. The quasi-c.w. probe power is limited by the c.w. saturation current of the photodetector to approximately 50 mW. The signal to noise is then limited by fluctuations in the relatively small number of photons during the 10 nsec gain pulse.

We have chosen to use a probe laser with a short pulse width (10 nsec) so as to be able to increase the probe power under the gain pulse. Initial experiments used the experimental configuration shown in Fig. 1. The probe power was sampled before and after the target with a FD100 photodiode from EGG, Inc. This diode was selected because of its wide bandwidth and large saturation current. We have found the diode to be linear up to 500 mA peak current. As first done by Nestor [10], the gain was measured by subtracting the diode signals using wideband differential amplifiers. The optimum configuration first integrated the diode signals using low noise charge preamplifiers and then subtracted the signals using a wide band amplifier. The error in subtraction over the full bandwidth was approximately 8% of the pulse height. A gated boxcar integrator was then used to sample the difference at the point best representing the total charge from the integrated signals. This technique reduced the subtraction error to 1% on a single shot basis, and when averaging over 1000 laser shots we could observe a gain or loss of the probe power of about one part in 10^4. The major limitation using the boxcar was our inability to average over the fluctuations in the power of the pump and probe lasers.

We next installed a computerized data acquisition system similar to that used for our two photon experiments [11,12]. The function of the boxcar is replaced by a gated, 11 bit, LeCroy charge digitizer. With this facility the signal can be normalized on a shot-to-shot basis to the laser powers sampled with additional diodes. At the same time we experimented with using faster differential amplifiers to subtract the signals in real time and then integrating. Several types of amplifiers were used with only slight improvement in the single pulse error over the previous approach.

Both techniques suffer because of the difference in bandwidth of the two diodes. In both of the above experiments we use "matched" diodes and attempted to further match the junction capacitances by varying the reverse bias voltages. We have now devised an elegant technique which uses a single diode to sample the beam before and after gain. This experimental approach is illustrated in Fig. 2. The basic idea is to delay one of the optical signals relative to the other using a low loss optical fiber. The two light signals are then combined onto a single diode to produce an electronic signal as shown at point B. If the second pulse is delayed sufficiently to allow the diode to recover, both light pulses are processed by an identical transfer function. The signal is then split and one half delayed (with cables) so as to bring the two signals into time coincidence again. We have subtracted the signals with amplifiers, or more simply, by using a clipping cable which delays, inverts, and sums the signals at point B. The resulting error is approximately 1% of the optical pulse; and fluctuations in the integrated error is reduced to 1 part in 10^4. This error is still approximately a factor of 10 worse than the shot noise limit for our diode currents of 200 mA. We believe the error is caused by reflections generated by imprecise impedance matching of the diode to the cable. We have purchased a 1 GHz linear amplifier in order to obtain better matching. With this improvement and averaging over large numbers of laser shots, we should obtain a significant increase in the state of the art for SRGS.

C. FOLLOW-UP STATEMENT

This work is continuing under joint services support. We feel we have made significant progress, and with planned improvements will have made a significant breakthrough in the sensitivity of SRGS. For detection of ions at densities of 10^{14} cm^{-3} we still need a significantly stronger pump laser. We have submitted proposals to the DoD equipment program in both 1982 and 1983 for this laser.

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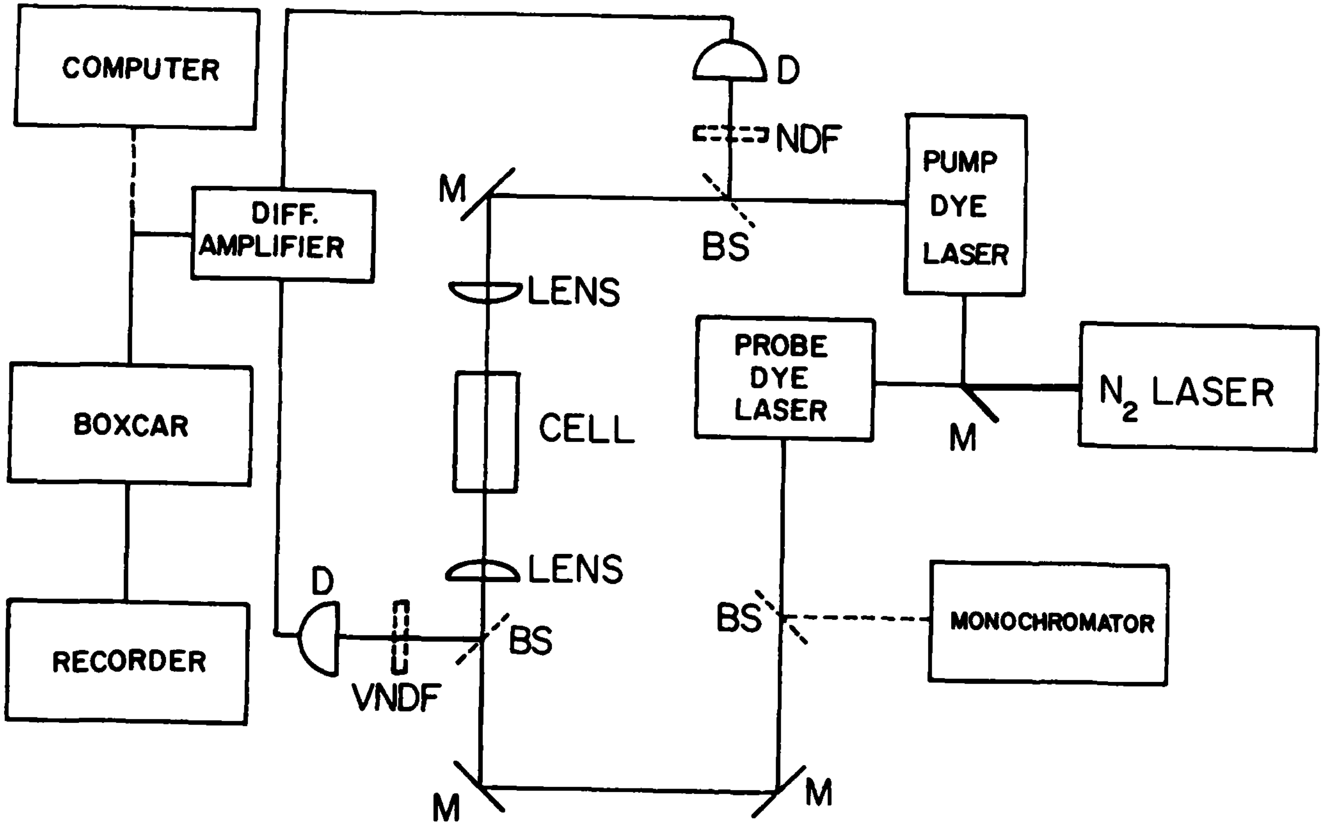

Fiture 1. SRGS apparatus using two diodes to sample the gain of a probe laser.

(Page 7, Res. Unit QE83-2 "Nonlinear Raman Scattering From Molecular Ions")

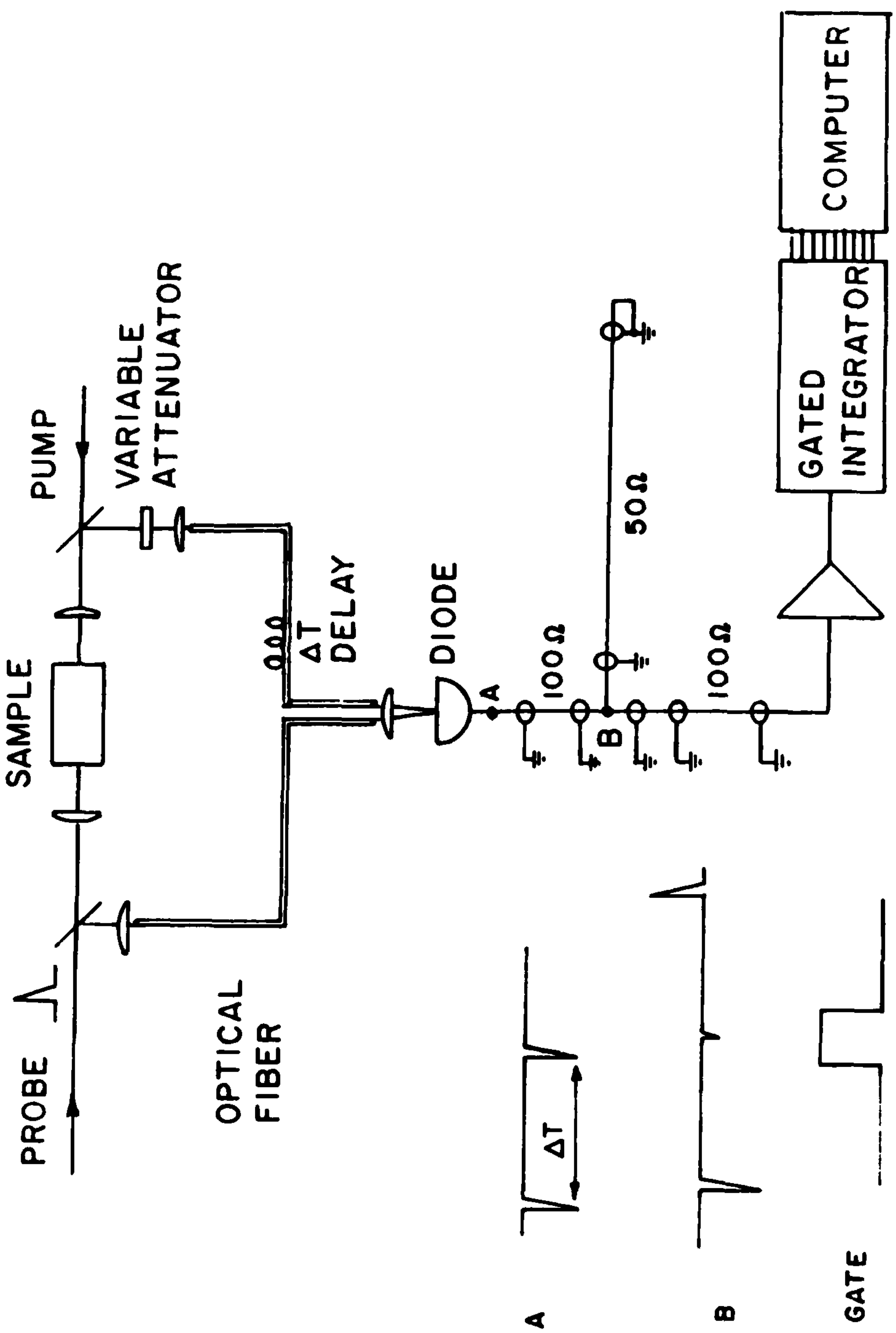

Figure 2. SRGS apparatus using only a single photodetector to measure the probe laser gain.

THE UNIVERSITY OF TEXAS AT AUSTIN ELECTRONICS RESEARCH CENTER
QUANTUM ELECTRONICS

Research Unit QE83-3 NONLINEAR OPTICAL INTERACTIONS

Principal Investigators: Professor M. Fink (471-5747)
Professor H.J. Kimble (471-1668)

Postdoctoral Associate: Dr. A.T. Rosenberger

Graduate Students: T.L. Boyd, S. Ketkar, R. Mawhorter, B. Miller, and L.A. Orozco

A. SCIENTIFIC OBJECTIVES: This research unit is work proposed by Drs. Kimble and Fink and deals with the interaction of atoms and molecules with resonant optical fields. The emphasis of the program is many fold: (1) to study the instabilities inherent in the nonlinear coupling of a collection of atoms to the electromagnetic field in the presence of feedback (as provided for example by an optical resonator), (2) to investigate circumstances in which microscopic quantum fluctuations can lead to macroscopic effects, (3) to measure the dynamic response of a single-mode, high power CW dye laser of the Michelson type to intracavity doubling when the UV itself is trapped in a resonance cavity of its own, (4) to test the influence of laser power and polarization on resonant and near resonant optical pumping of gas jets with the intent of efficiently producing aligned samples and (5) to understand the effect of very weak magnetic and electric fields on the selection rules and the coherence of magnetic hyperfine states. The general spirit of the work might be summarized by a statement such as "The investigation of nonequilibrium phase transitions in optical systems" (the laser is an example of such a transition).

Within this general context, part of the research program that has been initiated deals specifically with the phenomena of optical bistability and optical pumping. An optical system is termed bistable if, for a given value of input field, the output of the system can be multivalued. The actual output is determined by the position of the bistable device along a hysteresis cycle. In our experiments particular emphasis is placed upon the study of a "simple" system -- that is to say, a physical system which is on the one hand experimentally realizable while on the other hand is amenable to detailed microscopic analysis. Our experiments investigate bistability for a collection of "two-level" atoms (ground state and one excited state only) inside a high finesse optical resonator. In this arrangement the cooperative interaction of atoms with the electromagnetic field is free from certain "complicating" features such as collisions, degeneracies, or Doppler shifts. Our experiments thus make direct contact with an extensive theoretical literature [1-13] and provide a benchmark for the understanding of bistable systems in general.

These same comments apply to the interaction of multilevel atomic systems with resonant laser radiation. We propose to extend the understanding of optical pumping processes among nearly degenerate Zeeman and closely spaced atomic hyperfine levels. While rate equations provide an adequate description in many circumstances, in some cases of practical importance one must deal with the full density matrix of diagonal and off-diagonal elements (level to level coherence). Our goal is to explore the existing theory [14] and to apply this theory to realistic experimental conditions to produce aligned atomic ground or excited states.

The research program and its objectives that we propose for the coming years are discussed briefly and listed below.

(a) Characterization of the steady-states in optical bistability and the study of the stability of these states against external perturbations.

(b) Study of the fluctuations in bistability that arise from the quantum nature of the atom-field coupling.

(c) Investigation of dynamical behavior in bistability through measurements of transient response (i.e., switching characteristics).

(d) Exploration of instabilities in optical bistability leading to oscillatory or self-pulsing behavior.

(e) Optimization of optical pumping processes with respect to occupation numbers, state orientation and alignment.

(f) Influence of very weak magnetic and/or electric fields on fixing the underlying symmetry of optical interactions.

(g) Study of efficient intracavity U.V. generation with emphasis placed upon possible dynamical behavior.

B. <u>PROGRESS</u>: The linear and nonlinear interactions of light with matter involve very complicated processes. The most simplified cases which can be studied today with some success are two level atomic systems exposed to monochromatic coherent light. Even in this reduced form there are several open questions with regard to theory and experiment. While the monochromatic light is commercially available in the form of laser beams, the two level atomic systems are not easily accessible for an experiment. Sodium vapor has become the standard target system. This atom has strong resonances in the frequency region where tunable lasers work best and Na undergoes optical pumping cycles when illuminated with polarized photons. When 598.6 nm circular polarized photons are used, a sequence of excitation and emission depletes the hyperfine structure manifold with the exception of M(F) = 3 in the $^2P_{3/2}$ state and M(F) = 2 in the $^2S_{1/2}$ ground state [14]. The optically pumped Na system is the closest approach to the two level target we know today.

The experimental verification of the optical pumping mechanism was given in detail by Citron et al [17]. Their results agreed well with calculations using steady state rate equations. This success led to a series of experiments where optically aligned Na-atoms were involved. The density of the atoms, their degree of orientation, and their alignment were calculated on the base of Citron et al's results. Today much more powerful lasers are available and this leads to several new questions: Is there a power density and profile which maximize the efficiency for the production of aligned atoms? How many atoms are driven into the F=1 ground state and are carried as ballast in the subsequent experiment? To which extent does power broadening hurt or help the pumping process? Are the rate equations still adequate to describe the optical pumping process?

There are several experiments underway essentially extending the results of Citron et al. to higher power densities [18,19]. The quantities measured are the intensities and polarization of the fluorescence from the sodium beam. These data are relative and in order to compare them with theory, one has to rely on a matching process. If a significant fraction of the atoms are accumulating in the F=1 ground state, they are neglected in the evaluation and the final results are distorted. The data we are presenting here provide direct access to the analysis of the optical pumping process utilizing the ratio of absorption cross sections.

The experimental arrangement consists of a Na beam with a divergence of 2 arc minutes and 2 laser beams crossing the atoms exactly perpendicularly. The upstream beam is very intense, has a Gaussian profile, and is called the pumping beam, while the second laser beam is very weak, located 10 millimeters downstream from the pumping beam and is called the probing beam. Both laser beams originate from the same dye laser and their frequency is swept simultaneously at a slow rate to ensure adiabatic following of the atoms. Rather than measuring the fluorescence, the intensity of the probing beam is recorded as a function of frequency. Figures 1 and 2 show the absorption spectrum of the second laser without and with the pumping beam. In the first case (Fig. 1) the 3 hyperfine transitions are resolved, and the peak maxima follow closely the 1:5:15 ratio. The deviation from the exact integer ratios is due to some optical pumping by the weak probing beam. The line shapes show that the combined effect of Doppler broadening, the laser linewidth, the natural linewidth, and the finite residence time of the atoms in the laser beam is less than 13 MHz.

Figure 2 depicts the absorption spectrum when both laser beams are tuned through the D_2 transition at 598.6 nm. Since each atom goes through many optical cycles while crossing the intense pumping beam and since a magnetic guidance field of 1 gauss is carefully aligned parallel to the laser beams to avoid optical excitations, the atoms in the beam are forced into the M(F) = 2, F = 2 or M(F) = 1, F = 1 state of the $^2S_{1/2}$ manifold. The strength of the absorption signal at the center of the profile can be used as a measure of the success of the optical pumping process. The data collected with this arrangement give a value of 2.0 for the ratio of the absorption maxima. This value is independent of the atomic densities which reached up to $10^9/cm^3$. Note that this direct absorption method is independent of light trapping distortions, which hamper the fluorescence approach severely at high target densities. The magnetic guidance field minimizes the reoccupation of the Zeeman levels. A field inhomogeneity of 1% leads to an average loss of the M(F) = 3 state to the M(F) = 2 neighboring state of only 0.03% [20].

The absorption cross section is given by [21]

$$\sigma = \frac{1}{g} \sum_{i,j} \hbar\omega \, W_{ij}(F,M(F))/I_0$$

where g is the degeneracy of the final state and i,j are the summation indices of the initial and final states. $W_{i,j}$ is the probability per unit time of a transition from the initial state $(F,M(F))_i$ to the final state $(F,M(F))_j$. Assuming a Lorentzian absorption profile W_{ij} is given by

$$W_{ij} = \frac{1}{\pi} I_0 \cdot B_{ij} \frac{\Delta\nu_{homo}/2}{(\nu-\nu_0)^2+(\Delta\nu_{homo}/2)^2}$$

or

$$\sigma = \frac{\hbar\omega}{\pi(2F+1)} \sum_{i,j} B_{ij} \frac{\Delta\nu_{homo}/2}{(\nu-\nu_0)^2+(\Delta\nu_{homo}/2)^2}$$

where B_{ij} are the Einstein coefficients for induced transitions, and $\Delta\nu_{homo}$ is the natural linewidth of 10MHz. The B_{ij} values are listed in Ref. 21. At 589.6 nm and for the F=2 initial states

$$\sigma = 7.75\times10^{-10}cm^2$$

This value has to be compared with the two level system F=2 M(F)=2 and F=3, M(F)=3 where $B_{2,3}$ = 7.69 and g =1

$$\sigma_{2-\ level} = 1.66\times10^{-9}cm^2$$

Therefore

$$\sigma_{2-\ level}/\sigma = 2.14$$

This ratio is in excellent agreement with the experimental value of 2.0. These results show that only a very small fraction of the atoms are lost to the F=1 ground state in the optical pumping process, when the laser is tuned on resonance. The analysis of the rate equations shows that the atoms reach the F=3 M_F=3 states in the outer tail of the pump beam and therefore the detrimental effect of the power broadening can be avoided. It would be interesting to continue this research with apodized apertures to create sharp beam edges and thus expose the atoms suddenly to very high spectral densities.

The JSEP program has supported our electron diffraction work over many years. This work is now sponsored by the NSF. We continue to improve this technology in order to combine in the distant future our optical know-how with this work and therefore we continue to acknowledge the JSEP support [22-28], in particular in the development of new methods which will make this unique merger possible.

C. FOLLOW-UP STATEMENT: We intend to continue our work in cooperative and collective effects in nonlinear optical systems. Due to some additional funding we have extended our experimental facilities and several new arrangements will be tried to bring the experiment ever closer to the ideal conditions the theory requires to predict new phenomena. One of us (M.Fink) will spend the summer months in Kaiserslautern (Germany) and learn the technology to make apodized apertures.

This will open new possibilities in many of our experiments. The other investigator (J. Kimble) will have one year without teaching duties due to the Presidential Young Investigator Award. This will intensify our efforts and help to make significant progress.

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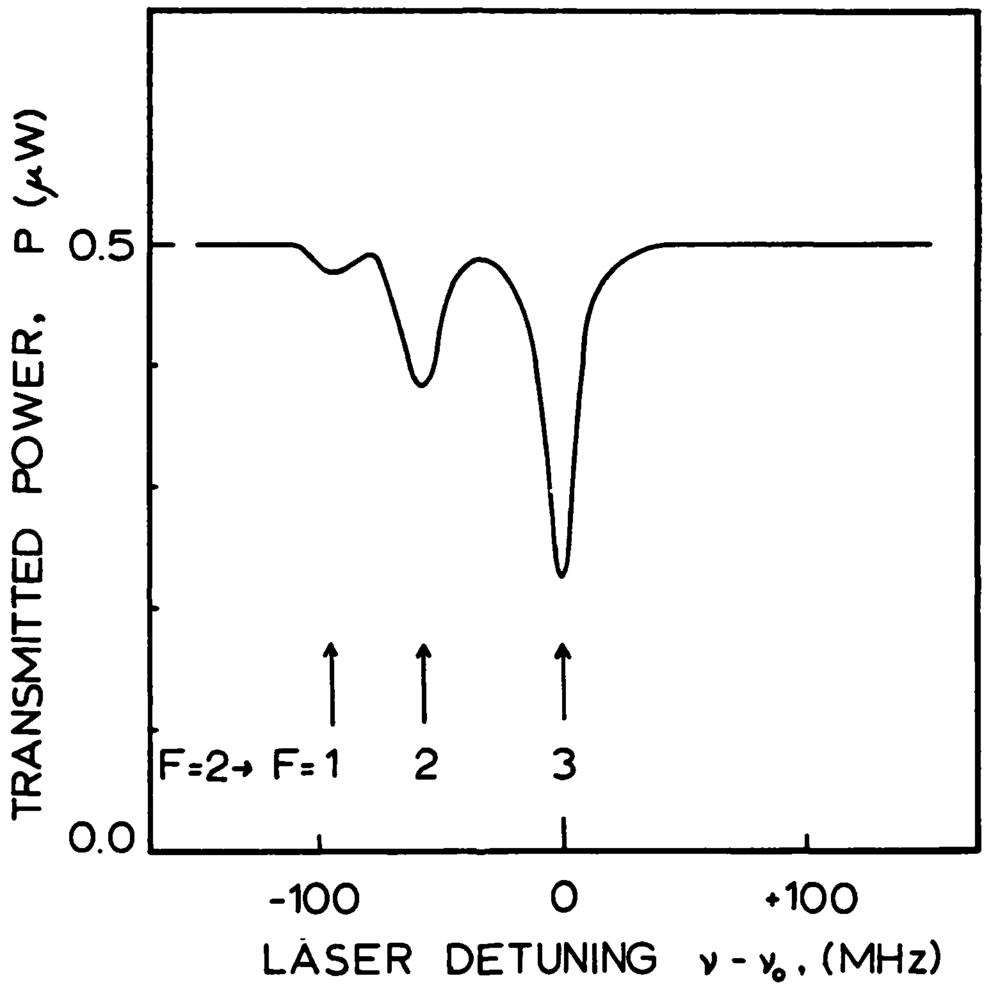

Figure 1. Absorption spectra for the $3^2S_{1/2}$, F=2, to $3^2P_{3/2}$, F=1,2,3 transitions in sodium without optical prepumping.

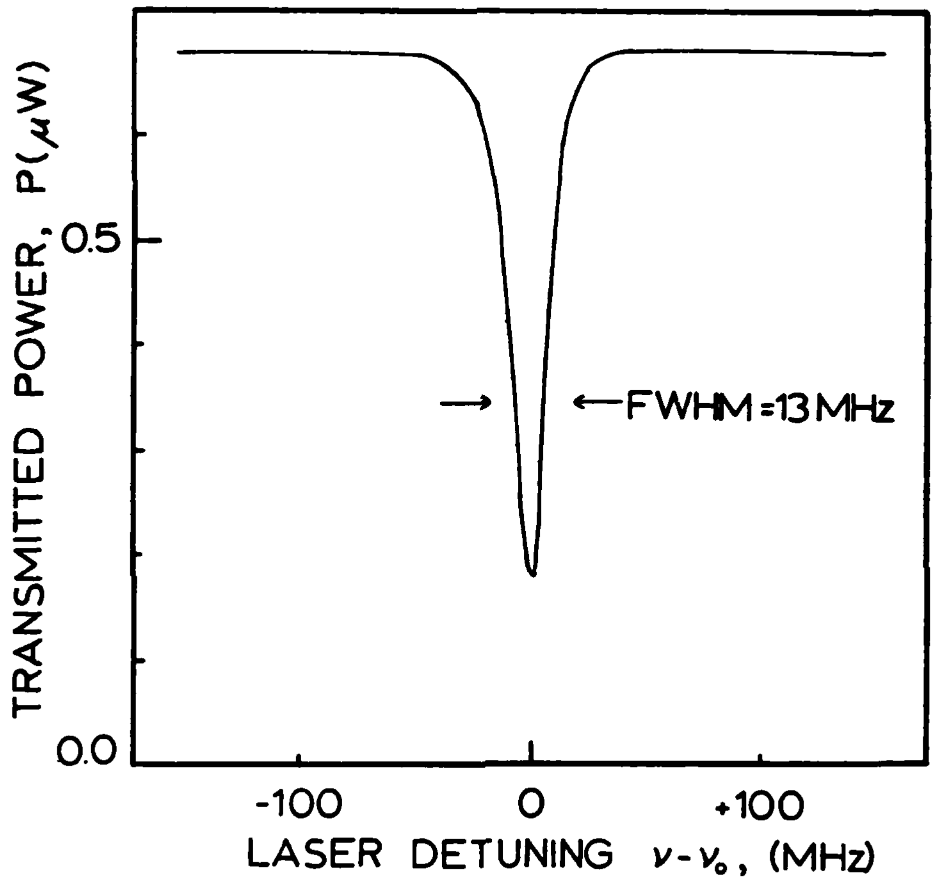

Figure 2. Absorption spectrum for the $3^3S_{1/2}$, F=2, M_F=2, to $3^2P_{3/2}$, F=3, M_F=3 transition with optical prepumping. Note the single absorption feature indicating the preparation of a "two-level" atom. The atomic number density is the same in Figure 1 and 2 with the increased absorption in Figure 2 due to the enhanced absorption cross-section for the "two-level" transition, as discussed in the text.

IV. ELECTROMAGNETICS

THE UNIVERSITY OF TEXAS AT AUSTIN — ELECTRONICS RESEARCH CENTER
ELECTROMAGNETICS

Research Unit EM83-1 GUIDED WAVES IN COMPOSITE STRUCTURES

Principal Investigator: Professor T. Itoh (471-1072)

Graduate Students: Yoshiro Fukuoka and Nag Un Song

A. SCIENTIFIC OBJECTIVES: Several guided wave structures will be studied for potential applications in millimeter-wave configurations. Analysis procedures will be developed and design data obtained for structures that contain semiconductor materials. Some experimental verifications will be performed. The primary objective is to identify and characterize structures which may lead to new functional device configurations for millimeter-wave integrated circuits, particularly in monolithic form. The second objective is to provide analytical foundations for several guided wave structures being used in millimeter-wave circuits that have not been extensively analyzed.

B. PROGRESS:

(a) Finline Discontinuities

A number of works have been done for characterizing discontinuities in microstrip lines. The results of these works are important in the monolithic circuit design because it is almost impossible and very expensive to adjust the monolithic circuit after fabrication. However, in millimeter-wave monolithic circuits, guided wave structures other than microstrip lines are frequently used. To date, only a few analyses have been performed on the discontinuities in slot lines, coplanar waveguides and finlines.

During this reporting period, an efficient method for analyzing finline discontinuities has been developed. The method consists of computing the resonant frequencies of a resonator obtained by short circuiting a finline section containing the discontinuities to be analyzed. The computation of the resonant frequencies is based on a transverse resonance technique. The field is expanded in terms of LSM and LSE modes of the waveguide housing. After the slot field is expressed in terms of a suitable set of functions, we obtain a set of homogeneous equations, the solution to which provides the resonant frequency. From this information, the parameters of the equivalent circuit of the discontinuities are extracted as a function of frequency and geometry.

The technique has been applied successfully to a step discontinuity between a narrow and a wide finline. The results have been compared with other data computed with a numerically much more laborious and inefficient technique. Agreement is found to be very good [1]. The present method has an advantage of notable reduction in computation time as compared to other numerical techniques. In addition, the algorithm is quite general and can be applied to a number of discontinuities with different shapes.

(b) Distributed Phase Shifters

The slow wave phenomena discovered by a number of researchers [2] have good potentials for applications in distributed electronic phase shifters suitable in monolithic circuit configurations. The major concern in using such a structure is the insertion loss inherently associated with the lossy semiconductor included in the structure. This slow wave phenomenon can be observed both in MIS and Schottky-contacted microstrip and coplanar waveguides.

Two analytical methods have been developed for analyzing these structures. Results by both methods correlate very well with each other as well as with measured data [3]. Since the analysis methods have been developed, they can be used for various purposes such as design and optimization.

An attempt has been made to reduce the insertion loss and at the same time to enhance the slow wave factor [4]. We studied a coplanar waveguide on a periodically doped semiconductor substrate. Reduction of the loss and enhanced slow wave factor at higher frequencies have been predicted. The latter is caused by the existence of the surface wave stopband created by the periodicity. Validity of these predictions have been confirmed by a simulation experiment [5].

The most interesting application of the slow wave effect in the foreseeable future is the development of an electronically variable distributed phase shifter. The electronic phase variation can be effected by changing the DC bias applied between the center and outer conductors of a coplanar waveguide with a Schottky-contacted center strip as shown in Fig. 1. This is because the size of the depletion layer can be adjusted by the DC bias, resulting in electronic control of the phase delay. For high frequency operation of such a device, it is important to reduce the attenuation caused by the semiconductor substrate. The method developed in the course of work described above has been applied to find the optimum conditions for both uniform and periodic Schottky contact coplanar waveguides as variable phase shifters. First, the optimum conductivity and the depletion layer thickness have been found for the electrode structures that do not cause breakdown for an appropriate bias and also do not increase the conductor loss excessively.

The parameters selected for GaAs substrate are: mobility 8500 cm^2/Vsec, doping density $3 \times 10^{17}/cm^3$, and depth of doped region 10 μm. Using these values, we calculated the length of the waveguide required for 180 phase change for the bias change of 0.2 to 1.7 V for both uniform and periodic structures. The associated maximum attenuations have been calculated. Example designs for 180^0 phase shifters for use up to 40 GHz are presented in Fig. 2. It is clear that advantages of the periodic structure diminish as the slot width is reduced [6-9].

(c) Traveling Wave IMPATT

Although IMPATT diodes are the best obtainable sources for a class of millimeter-wave circuits, their performance deteriorates as the frequency of operation increases. A traveling wave IMPATT is an alternative and is particularly suited for monolithic circuit applications. Fabrication of such a large area device became a reality only recently with the advent of molecular beam epitaxi (MBE). These devices have been recently developed at Texas Instruments Central Research Laboratory. Although there exists a number of analytical works on the traveling wave IMPATT, none of them is capable of analyzing a realistic structure.

In the present work [10], a complete set of differential equations governing both the wave propagation and avalanche multiplication is solved with boundary conditions including the finite conductivities of the metal contacts and the material losses. Small signal assumption has been made and the results have been obtained for a GaAs double-drift IMPATT diode under a traveling wave mode of operation. The cross section of the device is shown in Fig. 3. Numerical results for the oscillation frequency versus device length are shown in Fig. 4 for the device used as an oscillator with one end open and another short-circuited. The results are compared with the experimental results obtained at Texas Instruments [11]. They are in good agreement except for two black dots for which higher order resonance ($3\lambda/4$) takes place and the actual terminating condition might be more complicated.

(d) Finite Element Analysis of 3-Terminal Devices

This project started only very recently. It has been recognized that a number of emerging three terminal devices need an accurate simulation algorithm. These devices include low noise FET, HEMT and other hot electron devices. In the present period, a 2-dimensional model of a uniformly doped FET has been analyzed with a finite difference technique. As we gained confidence in this algorithm, we started developing a finite element analysis algorithm.

C. FUTURE DIRECTIONS:

(1) In actual finline circuits, an isolated step discontinuity is not frequently encountered. Often the discontinuities appear in tandem. Therefore, the algorithm developed for a finline discontinuity needs to be extended for cascaded finline steps. Examples are inductive notches and capacitance fins to be used in filter configuration.

(2) In the area of slow wave structures on a semiconductor substrate, an interesting subject is the interaction of two signals with different frequencies. Especially in a periodic structure, there exist possibilities of wave mixing, harmonic generation and frequency modulation. Feasibility of these phenomena will be investigated.

(3) In the area of traveling wave IMPATT devices, coupling and power extraction are important for a future study. Since the characteristic impedance of the traveling wave IMPATT is extremely low, a mechanism is needed that interfaces an external circuit that has the impedance level of typically 50 Ω. Several possible circuit techniques will be investigated in this area.

(4) The finite element analysis algorithm will be applied to a number of realistic devices such as recessed gate FET's once it is completely developed. However, the most pressing need is to study the FET's with graded doping for low noise applications. Although such a device has been suggested, no extensive analysis exists to date. The study for this problem provides useful information. In addition, we shall investigate applications of the algorithm for a HEMT device as well as more exotic 3-terminal traveling wave devices.

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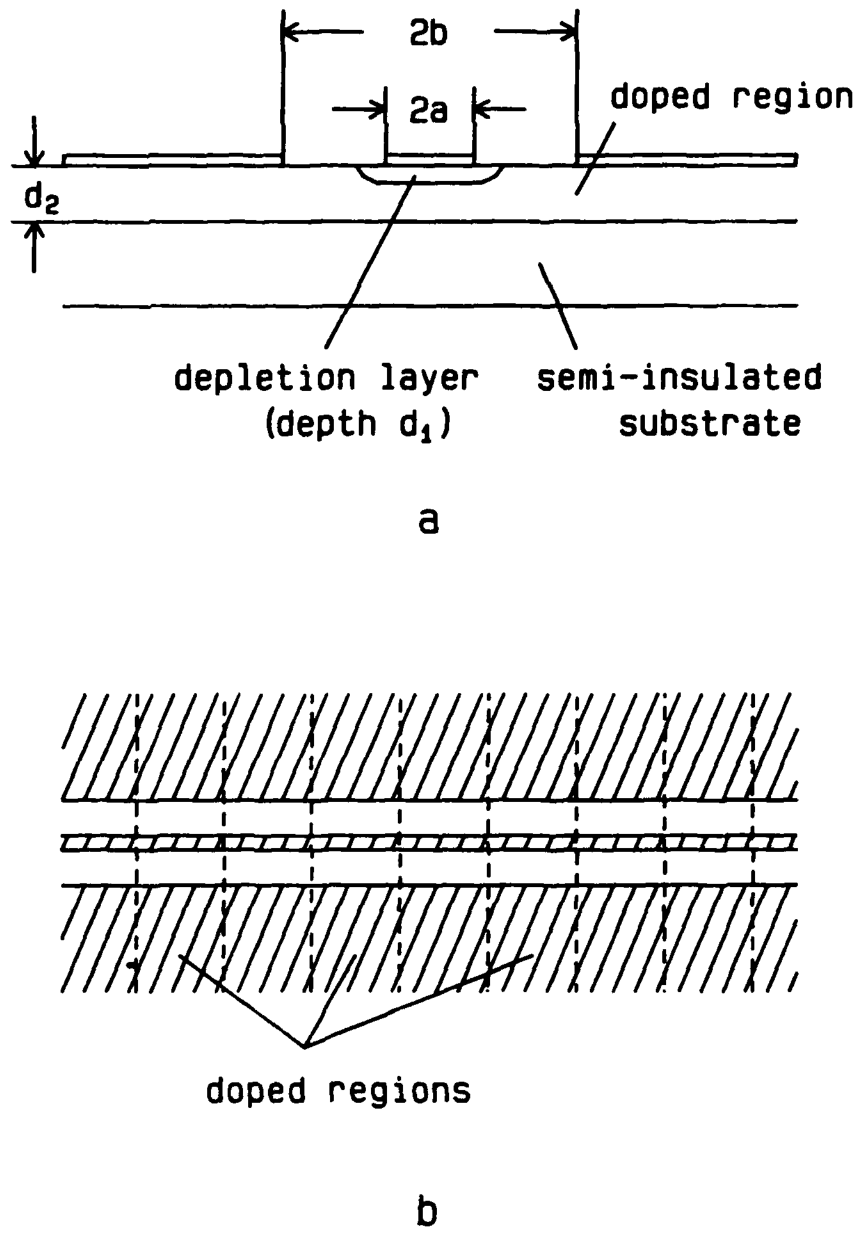

Figure 1. Distributed phase shifter (a) cross section (b) top view.

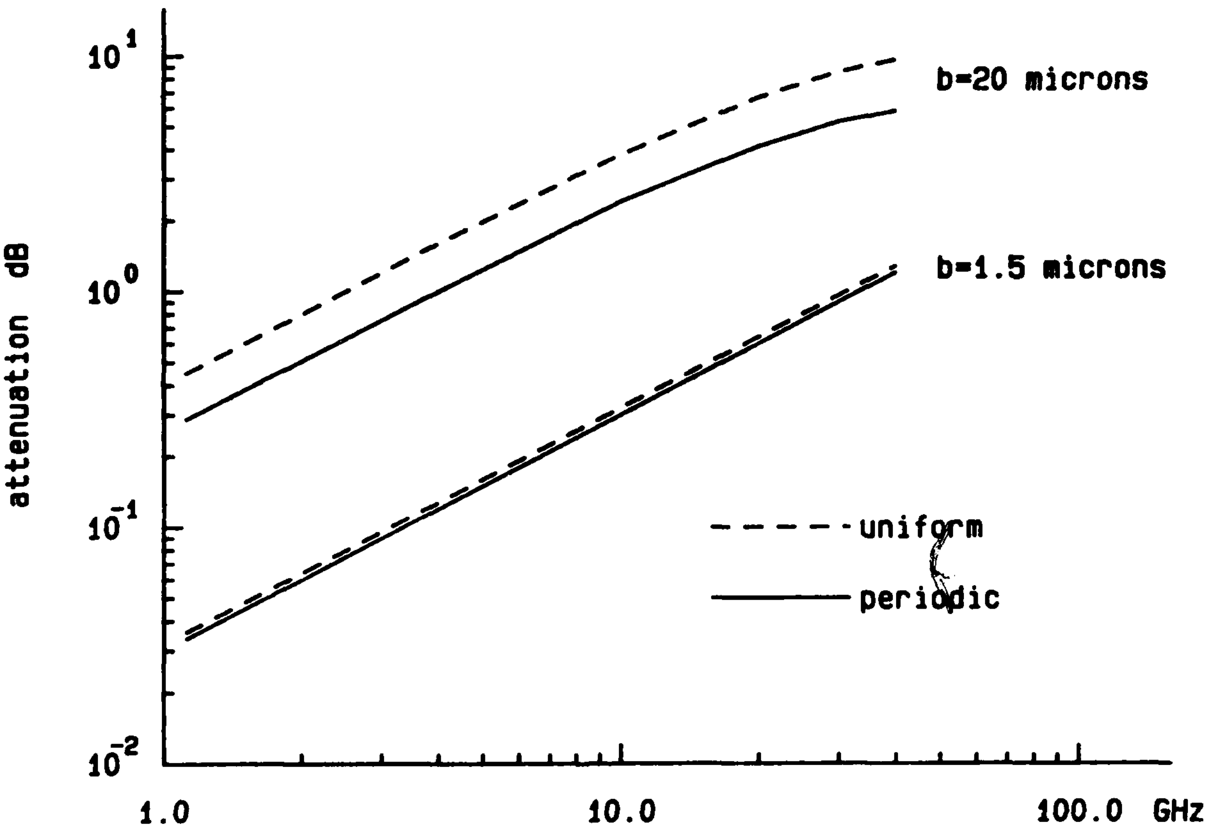

Figure 2. Insertion loss of distributed phase shifter.

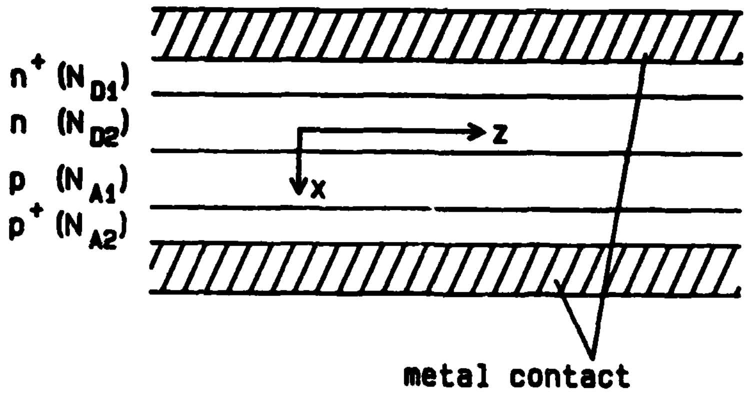

Figure 3. Side view of a traveling wave IMPATT.

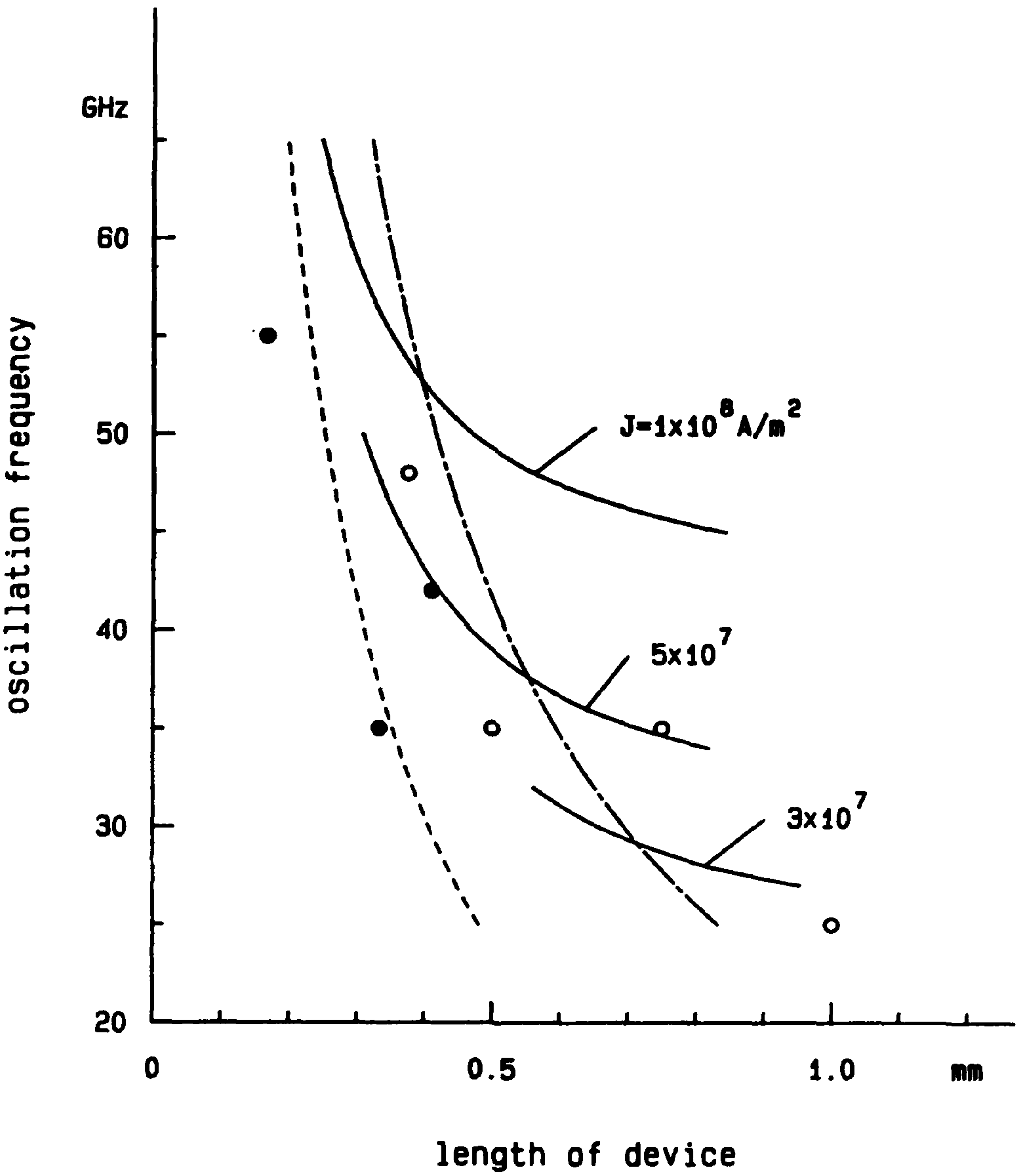

Figure 4. Oscillation characteristics of a traveling wave IMPATT.

RESEARCH GRANTS AND CONTRACTS

RESEARCH GRANTS

FEDERAL FUNDS

Defense Advanced Research Projects Agency, Contract F33657-84-C-2058, "Research on Advanced Thin Film Magnetodielectrics," Professor R.M. Walser, Principal Investigator, October 31, 1983-November 1, 1986.

Department of Defense Joint Services Electronics Program Research Contract F49620-82-C-0033, "Basic Research in Electronics," Professor E.J. Powers, Principal Investigator on behalf of the Faculty Affiliates of the Electronics Research Center, April 1, 1983-March 31, 1984.

Department of Energy, "Kinetic Studies Following State Selective Laser Excitation," Professor J.W. Keto, Principal Investigator, March 15, 1981-March 14, 1984.

NASA, Langley Research Center, "Determination of Fuel Optimal Flight Paths for Atmospheric Vehicles," Professor J.L. Speyer, Principal Investigator, May 1, 1983-July 31, 1984.

National Science Foundation, MEA 8211205, "Experiments on Spectral Energy Redistribution Due To Nonlinear Interactions and Phase and Amplitude Modulations During Transition to Turbulence," Profs. E.J. Powers and R.W. Miksad, Co-Principal Investigators, February 15, 1983-February 15, 1986.

National Science Foundation, ECS-8022033, "Lie Algebraic Methods in Nonlinear Estimation," Professor S.I. Marcus, Principal Investigator, March 15, 1981-August 31, 1984.

National Science Foundation, ECS-830-5340, Equipment for Digital Analysis in Stereo-scopic Light Microscopy, Profs.J.K. Aggarwal and Ken Diller, Co-Principal Investigator, August 1, 1983-January 31, 1985.

National Science Foundation, ECS 8 802-1511, "Computational Models for Processing Sequences of Bioengineering Images," Professor J.K. Aggarwal, Principal Investigator, May 1, 1981-October 31, 1984.

National Science Foundation, CHE 83-07174, "Experimental Determinations of Charge Densities by Electron Diffraction," Professor M. Fink, Principal Investigator, July 1, 1983-June 30, 1986.

National Science Foundation, ECS-8111616, "Investigation of Excess ("1/f") Noise and Dielectric Response of Non-Crystalline Structures Preceeding First Nucleation in Thin Film Systems," Professor R.W. Bene', Principal Investigator, November 15, 1981-April 30, 1985.

RESEARCH GRANTS

National Science Foundation, PHY-8211194, "Cooperative Atomic Activity in Optical Bistability (Physics)", Professor H.J. Kimble, Principal Investigator, January 1, 1983-June 30, 1986.

National Science Foundation, DMR-83-12013, "Synchrotron Radiation Beam Line," Professor J.L. Erskine, Principal Investigator, July 1983-June 1985.

National Science Foundation, DMR-83-04368, "Experimental Studies of Intrinsic Surface Electronic Properties - Metal and Semiconductor Surfaces," Professor J.L. Erskine, Principal Investigator, May 1983-October 1985.

Office of Naval Research, Contract N000014-79-C-0533, "Studies of Non-Reciprocal Effects in Planar Submillimeter to Optical Waveguiding Structures," Professor T. Itoh, Principal Investigator, June 1, 1980-August 31, 1984.

United States Air Force Armament Lab, Eglin AFB, Florida, "Investigation of Information Enhancement, Estimation, and Guidance Algorithms for Homing Missiles," Professor J.L. Speyer, Principal Investigator, October 1, 1981-September 30, 1984.

United States Air Force Office of Scientific Research, Grant No. AFOSR 84-0089, "Research in Adaptive and Decentralized Stochastic Control," Professor S.I. Marcus, Principal Investigator, March 15, 1984-March 14, 1985.

United States Air Force Office of Scientific Research AFOSR 79-0025, "Optimal and Suboptimal Estimation for Nonlinear Stochastic Systems," Professor S.I. Marcus, Principal Investigator, December 1, 1978-November 30, 1983.

United States Air Force Office of Scientific Research, F49620-83-K-0013, "Automatic Recognition and Tracking of Objects," Professor J.K. Aggarwal, Principal Investigator, December 1, 1982-December 31, 1984.

United States Air Force Office of Scientific Research/RADC, "Studies of Electrical Activation and Impurity Migration in Ion-Implanted Indium Phosphide," Professor B.G. Streetman, Principal Investigator, February 1984 through March 1985.

United States Air Force Office of Scientific Research/SCEEE, Professor M.F. Becker, Principal Investigator, May 1, 1983-August 31, 1983.

RESEARCH GRANTS

United States Air Force Office of Scientific Research/SCEEE, Professor M.F. Becker, Principal Investigator, February 1, 1984-December 1, 1984.

United States Air Force Office of Scientific Research, AFOSR-83-0131, "High-Resolution Electron Energy Loss Studies of Chemisorbed Species - Metal and Semiconductor Surfaces," Professor J.L. Erskine, Principal Investigator, April 1983-March 1985.

United States Army Research Office, DAAG29-81-K-0053, "Interface Structures for Millimeter-Wave Circuits," (additional funding), Professor T. Itoh, Principal Investigator, March 1, 1981-August 31, 1984.

United States Air Force School of Aerospace Medicine, Contract F33615-83-K-0610, "Solid State Electronic Gas Sensors," Profs. J.W. Barlow, D.W. Lloyd and R.M. Walser, Co-Principal Investigators, September 1, 1982-October 31, 1984.

United States Army Research Office, DAAG29-81-K-0053, "Interface Structures for Millimeter-Wave Circuits," Professor T. Itoh, Principal Investigator, March 1, 1981-August 31, 1984.

OTHER THAN FEDERAL GRANTS

Texas Atomic Energy Research Foundation Grant, "Analysis and Interruption of Plasma Fluctuation Data Utilizing Digital Time Series Analysis," Professor Edward J. Powers, Principal Investigator, May 1, 1983-April 30, 1984.

Texas Instruments, "Millimeter-Wave Transmission Lines Study," Professor T. Itoh, Principal Investigator, June 1, 1979-December 31, 1984.

University of Texas Equipment Grant, Professor B.G. Streetman, Principal Investigator, September 1982-June 1983.

Venture Research Unit of British Petroleum, Int., "Nonequilibrium Phase Transitions in Optical Systems," Professor H.J. Kimble, Principal Investigator, February 1, 1983-January 31, 1986.

Robert A. Welch Foundation, F-788, "Coherent Raman Spectroscopy of Molecular Ions," Professor J.W. Keto, Principal Investigator, June 1, 1980-May 31, 1983.

RESEARCH GRANTS

Robert A. Welch Foundation, F534, "Electron Scattering from Alkali Halide Vapors," Professor M. Fink, Principal Investigator, June 1982-May 31, 1985.

Robert A. Welch Foundation, F-789, "Momentum Redistribution by Resonant Radiation," Professor H.J. Kimble, Principal Investigator, June 1, 1980-May 31, 1983.

Robert A. Welch Foundation, F720, "Optical and Electron Spectroscopy Studies of Adsorbates at Metal Surfaces," Professor J.L. Erskine, Principal Investigator, April 1983-May 1984.

CONSULTATIVE AND ADVISORY FUNCTIONS

In June 1983, Professor E.J. Powers visited Dr. Ed Strickland at the United States Air Force Armament Technology Lab (Eglin) and Dr. V.B. Venkayya at the United States Air Force Avionics Lab (Wright Patterson) to discuss potential research involving applications of digital signal processing to important nonlinear aerodynamic phenomena.

Professor E.J. Powers visited Dr. Bill Von Winkle at the Naval Underwater Systems Center, New London, Connecticut in July 1983 and presented a seminar entitled "Applications of Digital Bispectral Analysis to Nonlinear Signal Processes," and discussed possible joint research programs.

Professor M.F. Becker has had a long term interaction with the Air Force Weapons Laboratory (AFWL) on the subject of laser induced damage. He received a SCEEE Fellowship to spend the summer of 1983 doing research at AFWL and will spend the summer 1984 there also under SCEEE sponsorship. Shorter meetings between Prof. Becker and AFWL personnel have been held in order to plan this research and a conference presentation. The AFWL individuals involved are Dr. A.H. Guenther and Dr. A.F. Stewart.

On October 20, 1983, Profs. S.I. Marcus and J.L. Speyer met with Mr. Jarroll Elliott, branch chief for controls technology at the NASA Langley Research Center, for an initiation meeting for their grant on periodic optimal aircraft cruise.

Dr. J.W. Mink of the Army Research Office visited T. Itoh on November 17, 1983 to discuss a number of subjects on millimeter-wave circuits.

On December 8-9, 1983, Dr. Jon Burns, Director of the Control Theory Progress at AFOSR met with Profs. J.L. Speyer and S.I. Marcus at U.T. for a briefing on stochastic control and estimation theory.

Professors J.L. Speyer and S.I. Marcus visited Dr. Lambert, chief scientist, on March 12, 1984 at the U.S.A.F. Armament Lab, Eglin AFB, to report on their progress over the last three year contractual effort on advanced homing missile guidance and to brief him on the ideas for their next three year effort.

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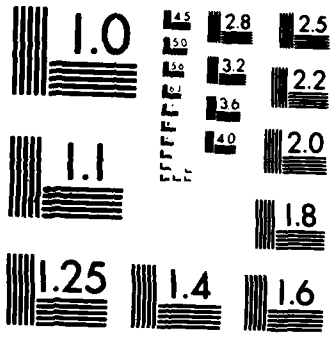

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5. TYPE OF REPORT & PERIOD COVERED: Annual Report for period 4/1/83-3/31/84

6. PERFORMING ORG. REPORT NUMBER: No. 31

7. AUTHOR(s): Edward J. Powers, Director; and other faculty and graduate research staff of the Electronics Research Center

8. CONTRACT OR GRANT NUMBER(s): Cont. F49620-82-C-0033

9. PERFORMING ORGANIZATION NAME AND ADDRESS: Electronics Research Center, University of Texas at Austin, Austin, Texas 78712

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 61102F 2305 A9

11. CONTROLLING OFFICE NAME AND ADDRESS: Air Force Office of Scientific Research (AFSC) AFOSR/NE, Bolling AFB, D.C. 20332

12. REPORT DATE: May 15, 1984

13. NUMBER OF PAGES: 77

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report): UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

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18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

INFORMATION ELECTRONICS; QUANTUM ELECTRONICS; SOLID STATE ELECTRONICS; ELECTROMAGNETICS

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report summarizes progress on projects carried out at the Electronics Research Center at The University of Texas at Austin and which were supported by the Joint Services Electronics Program. In the area of Information Electronics progress is reported for projects involving (1) nonlinear estimation and detection, (2) electronic time-variant signal processing, and (3) digital time series analysis with applications to nonlinear wave phenomena.

In the Solid State Electronics area recent findings in (1) solid state interface reactions and instabilities, (2) electronic properties and structure

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) of metal silicides and interfaces, and (3) implantation and interface properties of InP and related compounds are described.

In the Quantum Electronics area progress is presented for the following projects: (1) quantum effects in laser induced damage, (2) nonlinear Raman scattering from molecular ions and (3) nonlinear optical interactions.

In the Electromagnetics area progress in guided waves in composite structures is summarized.

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